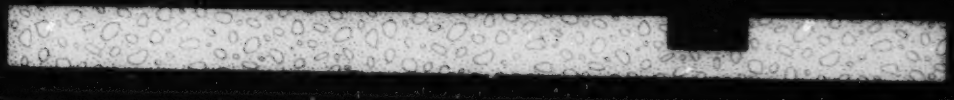
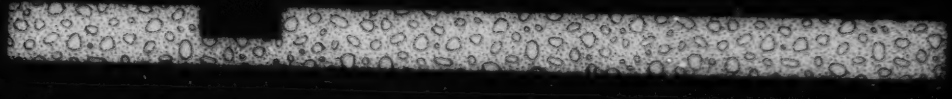
Developing a Weigh in Motion Highway Scale





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DEVELOPING A WEIGH-IN-MOTION HIGHWAY SCALE

AN RTAC PROJECT

Prepared for the

Roads and Transportation Association of Canada
Project Committee on Monitoring
Vehicle and Axle Weights

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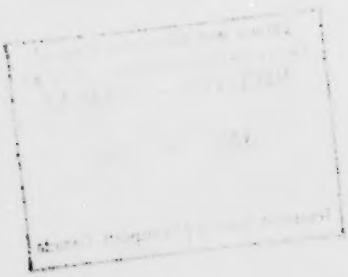

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17. Abstract

A Project Committee was formed in 1976 under the auspices of the Roads and Transportation Association of Canada to evaluate weigh-in-motion systems and make recommendation respecting their suitability to the Canadian environment. A number of systems were evaluated. The system developed by the University of Saskatchewan was installed and evaluated in four provinces. Numerous operational problems were encountered during the evaluation period; however, all of these problems appear to have been resolved and the University of Saskatchewan system would appear to be suitable for application in the Canadian environment. These systems, as of 1982, have operated trouble-free on an unmanned continuous basis for periods of up to one year. The units have been used for data collection at highway speeds, pre-screening devices at permanent scales used for enforcement of axle and gross vehicle weight regulation, and as slow roll-over scales.

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17. Résumé

Un comité de projet fut créé en 1976, sous les auspices de l'Association des routes et transports du Canada, pour évaluer les bascules de pesage dynamique disponibles et faire des recommandations au regard de leur compatibilité avec l'environnement canadien. Le projet a porté sur un certain nombre de systèmes de pesage dont un conçu par l'université de la Saskatchewan et mis à l'essai dans quatre provinces. Les nombreux problèmes d'ordre opérationnel rencontrés au cours de cette période d'évaluation semblent avoir été résolus; selon toutes les indications, la bascule de l'université de la Saskatchewan est compatible avec l'environnement canadien. À la fin des essais (1982), elle avait fonctionné automatiquement, en permanence et sans détraquement pendant des périodes allant jusqu'à 12 mois. La bascule a servi d'une part à la collecte de données sur les véhicules se déplaçant à grande vitesse et, d'autre part, comme dispositif de présélection aux stations de pesage statique utilisées dans l'application des règlements sur les charges à l'essieu et le poids total en charge des véhicules et comme bascule de pesage au ralenti.

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ROADS AND TRANSPORTATION ASSOCIATION OF CANADA

PROJECT COMMITTEE ON MONITORING VEHICLE AND AXLE WEIGHTS

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Project Manager:	B.E. Hicks	Roads and Transportation Association of Canada
Members:	B.P. Shields	Research Council of Alberta
	A.T. Bergan	University of Saskatchewan
	R.W. Culley	Saskatchewan Department of Highways and Transportation
	G. Tessier	Ministère des Transports du Québec
	H. Page	New Brunswick Department of Transportation
	I.F. Gilbert	Transport Canada, Transportation Development Centre

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New Brunswick Department of Transportation

1. INTRODUCTION

1.1 Background

One of the most striking features of our economy and way of life is our increasing dependence upon highway transportation. We depend upon highways for the movement of goods, for travel to and from work, for social and recreational purposes, and directly or indirectly for most other functions inherent in our complex society.

Canada has one of the most extensive and modern highway systems of any country in the world. There are more than 884,000 kilometres of roadways within Canada, of which in excess of 250,000 kilometres are paved (1). Annual expenditures in Canada by senior levels of government on highway construction and maintenance exceed 4.1 billion dollars (2).

The highway system within Canada consists of a hierarchy of roadways including urban and rural freeways, arterials, collectors and local streets. Two principal components of this highway system are roadway and bridge structures. It is the planning, design, construction, operation and maintenance of these roadway and bridge structures that consumes a major portion of all highway expenditures.

1.2 Roadway Structures

Roadway structures for major roads, on which the majority of all vehicle travel takes place, typically consist of the natural soil of the subgrade plus granular subbase and base layers covered by an asphalt or portland cement concrete pavement. Among the primary determinants relative to the service lives of highway pavements, both asphalt and portland cement concrete, is the amount of truck traffic, and more particularly the weight of truck axles, and the number of axle load repetitions. Modern highways are designed to withstand a specific number of load repetitions of a specific magnitude over a selected future period of time - this time being the anticipated service life.

The design procedure most often used involves the prediction of the number and weight of truck axles which will pass over the highway during a given time period in the future. The varying anticipated axle loadings are usually converted through the use of an empirically derived relationship, to equivalent axle loads of a fixed magnitude, usually 8.16 tonnes.

The projected number of equivalent axle loadings is the design basis for determining the roadway structure required and the thickness of pavements that will be built, and therefore its' cost. The actual number of equivalent axle loadings passing over a highway determines the service life of the pavement. That is, unlike many other types of structures, roadway structures do not typically fail catastrophically, but rather the pavement surfaces slowly deteriorate in riding quality, safety, structural capacity and structural integrity with the passage of traffic and time. In short, a pavement is slowly "consumed" by the traffic that it is designed to accommodate.

Once a pavement surface has deteriorated to the point that it no longer provides an acceptable level of service, the pavement surface can be rehabilitated. The timing of the rehabilitation is important in that if it is undertaken too soon, cost inefficiencies are introduced because the total productive life of the original pavement has not been utilized. On the other hand, if the rehabilitation is delayed too long, the costs associated with rehabilitation increase dramatically because of the loss of structural integrity of the roadway structure.

There are numerous trade-offs possible in the design of roadway structures. Thickness of various layers can be varied, as can materials used. Also, pavements can be designed for different service lives with the resulting trade-off between initial construction costs, maintenance and rehabilitation timing and costs.

The cost implications of these decisions is aptly demonstrated by the fact that if "optimizing" decisions related to design, construction and maintenance of the highway system in Canada could result in savings of 1%, savings would amount to an estimated 40 million dollars annually.

While there are innumerable determining parameters involved relative to the highway system generally and pavement surfaces in particular, the single most important parameter for pavement structures is the number and weight of truck axles.

1.3 Bridge Structures

Concerns related to loading of bridge structures are somewhat different than those for roadway structures. In the case of bridges, it is a combination of axle load, axle spacing and gross vehicle weight that must be accommodated, both in the design and the subsequent use of the structure. Under normal conditions, if the bridge is not "overloaded" relative to the loads for which it was designed, the live loads imposed upon the structure do not play a primary role in determining the service life of the structure. In most cases, deterioration associated with environmental conditions play the determining role relative to the service lives of highway bridges. This is not to imply that vehicle loadings are not important.

Axle loads, axle spacings and gross vehicle weights are usually specified by a bridge formula that is commonly used to regulate and control loads that can be safely applied to bridges. This formula defines the combination of permissible axle loads, axle spacings and gross vehicle weights. In short, bridge structures can be damaged by loads transmitted to them via axles which are too heavily loaded and/or improperly spaced, or by too heavy gross vehicle loads.

1.4 Data Requirements

From the above, it can be concluded that highway engineers have a keen interest in information related to the number and weight of axles, axle spacings and gross vehicle weights in that these parameters are the determinants of the service lives of pavements, and play important roles relative to bridge structures.

Highway engineers expend considerable effort in attempting to determine, as accurately as possible, the number and magnitude of axle load applications experienced by a highway as well as attempting to ensure that excessive loads are not imposed upon pavement or bridge structures.

Data related to the number, weight and spacing of axles and gross vehicle weights is typically obtained from a combination of continuous and short-term vehicle counts, vehicle classification surveys, and axle and gross vehicle weight surveys. Automatic equipment is available to count and classify vehicles as well as to determine axle spacings. Axle weights and gross vehicle weights have typically been obtained by surveys at permanent weigh scales used for enforcement of axle and vehicle weight regulations, or via the use of portable roadside scales. The information obtainable from the permanent weigh scale locations is limited by the number of locations. Also, this data is potentially biased due to the enforcement nature of the primary activities at these permanent scales. The use of portable scales is limited by the manpower requirements, the delays imposed upon the motoring public, and the safety hazard created by such activities.

1.5 Weigh-In-Motion Systems

Recognizing the need and desirability of improved data related to the number, weight and spacing of axles and gross vehicle weights, highway engineers from a number of countries in the past three decades have attempted to develop a scale that would weigh vehicles in motion. Attempts at developing a weigh-in-motion system were first reported in the United States by O.K. Norman and R.C. Hopkins in 1952 (3). Since that time, others from the United States, South Africa, Germany, Sweden, England and Canada have worked on the development of weigh-in-motion systems. A number of these systems reached the market by the late 1960's and early 1970's.

During the early 1970's, a number of provincial highway departments within Canada initiated programs related to weigh-in-motion systems. Ontario and Alberta purchased and tested the Viatec system developed in South Africa, while New Brunswick purchased and tested a system developed in Texas. Ontario also had a program related to the development of a system capable of determining whether or not a truck axle was overweight. At this same time, attempts were being made at the University of Saskatchewan to develop a weigh-in-motion scale.

In 1976 a Project Committee on Dynamic Weigh-In-Motion Systems was established in Canada under the auspices of the Roads and Transportation Association of Canada (RTAC). Participating agencies included the Saskatchewan Department of Highways and Transportation, Ontario Ministry of Transportation and Communications, Ministère des Transports du Québec, University of Saskatchewan, Alberta Department of Transportation, Transport Canada, Transportation Development Centre, and New Brunswick Department of Transportation.

An ambitious work program was undertaken by this Project Committee between 1976 and 1979. This report, which draws heavily upon two previous reports prepared by the Project Committee, describes the program undertaken and summarizes the results and conclusions of the RTAC Project Committee activities (4).

1.6 Report Outline

Chapter Two presents an overview of weigh-in-motion systems which have been developed. Chapter Three briefly outlines the Canadian experience with weigh-in-motion systems prior to the formation of the RTAC Project Committee. Chapter Four outlines the initial objectives of the Project Committee and the program that was undertaken by the Committee. The University of Saskatchewan weigh-in-motion system and its' development during the RTAC Project are described in Chapter Five. Chapter Six summarizes the experience with the University of Saskatchewan system at five locations across Canada between 1977 and 1979, and the results of accuracy tests carried out on the scale system. Chapter Six also outlines the status of the University of Saskatchewan scale since the completion of the RTAC Project Committee activities in 1979. Chapter Seven presents the conclusions drawn from the Project.

2. WEIGH-IN-MOTION SYSTEMS

2.1 Introduction (5)

A number of weigh-in-motion systems have been developed which are capable of obtaining and recording, on a continuous basis, the actual load measurements of the total vehicle population passing a given point at highway speeds.

2.2 Early Scales

Early attempts at developing a weigh-in-motion system were reported by O.K. Norman and R.C. Hopkins in 1952 (6). The scale consisted of a concrete slab about one by three metres and 400 mm thick, which was supported flush with the road surface by four conventional load cells set in a pit beneath the road. Electrical signals from the load cells were recorded for analysis. Several scales of this general type were installed in the 1950's and early 1960's in the United States.

There were a number of inherent design deficiencies which limited the success of this type of scale. From an installation and operations point of view, the scales involved a major initial effort and were limited to one location. Considerable difficulty was experienced with moisture in the pits and subsequent damage to equipment. Also, the inertia of the weighing platform plus its horizontal translation had adverse effects on the response of the system to dynamic loads.

Following these early efforts in the U.S.A., attempts to develop weigh-in-motion systems were initiated in a number of countries around the world. These weigh-in-motion systems can be generally classified into three categories based on the design principle utilized.

The first group which would include the early efforts in the U.S.A. consists of a weighing platform resting on load cells which are in turn supported by a foundation frame. Weigh-in-motion systems of this basic type differ from each other in terms of the kind of load cells and support frames utilized. Systems of this type have been developed in the U.S.A., Great Britain, Sweden, Germany, France and Japan.

The second group of weigh-in-motion systems utilize weighing plates equipped with strain gauges, wherein the extension of the underside of the plate is proportional to the load applied. A weigh-in-motion system utilizing this principle has been developed in Germany.

The third general group of weigh-in-motion systems operate on a capacitance principle utilizing a sandwich arrangement of rubber and metal compound. The change in capacitance resulting from an applied load on the rubber-metal mat is proportional to the load and is measured by electrodes connected to the variable capacitance mat. Units of this type have been developed in South Africa, Great Britain, Sweden and Austria.

2.3 British Systems

In 1957 the British Transport and Road Research Laboratory developed a system similar to that previously reported by O.K. Norman et al in the U.S.A. An improved model was developed in 1963. As of 1978, these units were still in use at 30 locations throughout Great Britain. In recent years, efforts at the Transport and Road Research Laboratory have been directed to the development of a capacitance type weigh-in-motion mat similar to the Viatec system developed in South Africa and described in a later section.

2.4 German System

A dynamic weigh-in-motion system similar to the first American system was developed in Germany at the Technical University in Stuttgart. This particular system was installed at a site near Grunbach.

A number of other weigh-in-motion systems have been developed in Germany since 1964, one at the Technical University in Hanover, two by the German Bundesanstalt für Strassenwesen (BAST), and another by Messrs. Messdata.

The system developed at the Technical University in Hanover consisted of 16 square strain gauge equipped load cells 500 mm on a side and 120 mm high placed in a concrete channel and covered with a 40 mm thick layer of asphaltic concrete.

One of the systems developed by BAST consisted of a hydraulic threshold unit operating on the hydraulic displacement principle. Two steel plates were welded together at the edges with a two to three millimetre space between them. The cavity was filled with a silicon-oil mixture which, when forced out by a load applied to the plates, caused deflection of a diaphragm that in turn was measured by an inductive linear displacement transducer. Development and testing was carried out on this system between 1964 and 1972. In 1972, the first of a total of 31 counting locations were equipped with this system.

Another weigh-in-motion system developed by BAST consists of steel plates with two milled grooves in the underside. Strain gauges are attached in the grooves. A signal which is a linear function of the load applied to the plate is generated by the strain gauges. Since 1973, this type of weigh-in-motion system has been installed at more than 70 locations within the Federal Republic of Germany. This type of system is manufactured by two firms under the BAST patent. Messrs. Messdata, Bornheim Hersel / Bonn were the first to build the system. It was essentially used for static and slow roll-over applications and later used for dynamic weighing. The electronics available consist of an analog weight catorization system which records on either a punch paper tape or a tape cassette.

Messrs. PAT (Prozess - Automatisierungstechnik) Ettlingen/Karlsruhe have also manufactured the system using the BAST patent since 1973. The PAT system is essentially the same as the one manufactured by Messrs. Messdata. Messrs. PAT do however also offer a system which utilized a micro-computer in the data acquisition system. Units using the BAST patent and manufactured by PAT are installed throughout the Republic of Germany as well as in some foreign countries, including Switzerland,

Australia, Belgium, Brazil, Finland, Netherlands and Poland.

Another system developed by Messrs. Messdata utilizes a pressure sensitive cable. The cable consists of a copper mantle and an internal copper conductor. The space between the mantle and the internal conductor is filled with a piezoelectric ceramic material. The cable is installed in a groove in the roadway. A load applied to the road surface results in deformation of the road structure which in turn results in a pressure on the piezoelectric cable. An electric charge is produced which results in a voltage difference proportional to the applied load. The deformation of the road structure is a function of temperature and vehicle speed. Units of this type are in use in about 50 locations throughout the Federal Republic of Germany.

2.5 French System

A weigh-in-motion system was developed in France in 1967 by the Laboratoire Central des Ponts et Chausees. The French system determines the load by using three piezoelectric quartz crystals which support a weighing platform. The deformation of the quartz crystals under load produces an electric signal which is led to a preamplifier and on to the data acquisition system. The most recent data acquisition system involves the use of a micro-computer which is capable of providing in addition to axle weights, information on axle spacing, vehicle lengths, gross vehicle weight and vehicle speed. Since 1969, more than 50 units have been installed in France with another 10 units being installed in foreign countries.

2.6 South African System

The National Institute for Road Research in South Africa initiated development of a weigh-in-motion system in 1967. This unit consisted of a rubber and metal mat 6 mm thick which changed in capacitance when compressed under a load. This system, known as the Viatec Axle Weight Analyzer, was until recently, produced by Plessey South Africa Ltd. The Viatec system has been tested in Australia and Canada. At present, the device is not available because production has ceased. According to the National Institute for Road Research, work is going on to improve the mat to increase the precision and reduce the sensitivity to temperature and humidity.

2.7 Texas System (7)

A weigh-in-motion system which utilized transducers was designed and manufactured in 1963 at the University of Texas under a joint program between the University of Texas and the Texas Highway Department. This device was field-tested over a number of months with the subsequent manufacture in 1965-66 of a second unit of a similar design plus an instrumentation system. This second unit was also field-tested, resulting in further design changes associated with sealing the electrical components, plus modifications to fabricating techniques prior to the manufacture of a third version during 1967 by the Rainhart Company of Austin, Texas.

Even though the 1967 design was an improvement over the previous designs, some problems related to sealing the unit persisted, and others related to distortion of the cast aluminum chassis were created. A subsequent model designated as the Model 880 by the Rainhart Company incorporated further modifications. This particular model was marketed by the Rainhart Company and was purchased by a number of highway agencies throughout the United States and Canada.

2.8 Japanese System

The Japan Highway Public Corporation has developed a system which has been installed at every toll point on Japan's motorway network in order to prevent overloaded vehicles from using the motorway. The weighing system consists of a weighing platform supported by 4 load cells placed on a rugged foundation frame. In addition to overload control, the system is used to collect statistics on commodity movements by motor carrier throughout Japan.

2.9 Other Systems

A number of other systems have been, or are currently being, developed. In 1960, the Swedish State Road Research Institute developed a system similar to the first American system. Also in 1960, a system was developed at the University of California. This system consisted of a girder frame instrumented with strain gauges.

A system which utilized a capacitance principle similar to that used in the Viatec system from South Africa is currently under development by the Swedish firm Telub AB, Växjö. The Austrian firm Semperit and the Transport and Road Research Laboratory in Britain are also developing similar units.

A system similar to that developed by the Technical University in Stuttgart was developed in Denmark, however these efforts have since been abandoned.

A modified version of the system developed under the BAST patent is being developed in the Netherlands at the Rijkswegenbouwlaboratorium in Delft. A data acquisition system which utilizes a micro-computer is under development at the Rijkswegenbouwlaboratorium.

3. CANADIAN EXPERIENCE WITH WEIGH-IN-MOTION SYSTEMS PRIOR TO 1976

3.1 Introduction

A number of programs related to weigh-in-motion systems were initiated in Canada in the early 1970's. The activities undertaken by these programs from the time of their initiation up to the formation of the RTAC Committee in 1976 are briefly described in the following sections. Developments subsequent to 1976 are described in Chapter Four.

3.2 Ontario Ministry of Transportation and Communications

A prototype model of the Viatec Axle-Weight Analyzer was obtained by the Ontario Ministry of Transportation and Communications in 1971 for testing. Fourteen sites with average daily traffic volumes between 1100 and 9600 vehicles were sampled for periods of from one to six days.

Some problems were encountered with the prototype, mainly related to moisture intrusion and fragile electrical connections. The rubber undersurface on one pad delaminated after approximately 175,000 axles. The unit was tested only during dry, non-freezing conditions and was under continuous supervision.

While no tests were done by the Ministry where the axle weight classification results from the Viatec weigh-in-motion system were compared with static weights, it was felt that the use of the system would produce a more realistic approximation of actual axle loadings on the highway than traditional methods of multiplying the total axle count by a fixed percentage. In short, it was generally viewed that the system had some potential for application in Canada.

In addition to the testing of the Viatec system, the Ontario Ministry of Transportation and Communications also initiated the development of a weigh-in-motion system known as the Truck Axle Weight Sorter. This system consisted of a horizontally restrained platform fastened to a concrete foundation by six bolts. Linear variable displacement transducers measured the imposed strain on the bolts when a vehicle passed over the platform. A prototype of this scale was installed east of Toronto on Highway #401, in the approach to a permanent weigh scale installation. Some difficulties were encountered in the development of a data acquisition and analysis system. These difficulties were primarily related to the processing of signals from the multiple transducers. The system did, however, appear at this stage of development to have considerable potential.

3.3 Alberta Department of Transportation

At approximately this same time, the Alberta Department of Transportation also obtained and tested a Viatec system. They too used the Viatec system at a number of sites, and also experienced difficulties

similar to those experienced in Ontario. They concluded that the system offered some potential if the operational problems could be overcome.

3.4 Saskatchewan Program

In 1972, a project to develop a weigh-in-motion system was initiated at the University of Saskatchewan. The design for the University of Saskatchewan scale was produced in recognition of the need for improved axle weight data and was an endeavor to produce a rugged and reliable system that would weigh vehicles at highway speeds on a continuous basis. Particular emphasis was directed at attempting to overcome some of the problems encountered with previous design attempts elsewhere - the most apparent of which were insufficient mechanical strength, and in the case of multiple load cell arrangements used by some other systems, technical difficulty in instrumentation.

The first prototype scale was designed and fabricated in the Engineering Shops at the University of Saskatchewan during 1973. This prototype was initially tested in the shop and then in an abandoned section of roadway using a test vehicle. This field test was a cooperative effort between the Saskatchewan Department of Highways and Transportation and the University of Saskatchewan.

The results of these initial tests proved encouraging and the scale was later installed in a section of highway north of Saskatoon. The results of tests at this site were also encouraging and led to the development of an analog data acquisition system. In 1975, the scale was removed from the site north of Saskatoon and installed in a section of highway near the town of Clavet, about twenty kilometres east of Saskatoon at a location near a permanent weigh scale installation used for enforcement of axle and vehicle weight regulations. The testing, evaluation and modification of the system continued at this site through to 1976 as a joint effort between the University of Saskatchewan and the Saskatchewan Department of Highways and Transportation.

3.5 New Brunswick Department of Transportation

In the fall of 1974, the New Brunswick Department of Transportation purchased a scale unit from the Rainhart Company of Texas and installed it in the Trans-Canada Highway near Fredericton. As a result of limited funds for the project at the time, the electronic data acquisition system that was designed to be used in conjunction with the scale was not purchased. Instead, the evaluation tests were conducted using a storage oscilloscope to store traces of the impulse generated by the vehicle axle on the scale with those being converted to weights using a static weight conversion factor.

Evaluation tests were conducted on seven separate occasions from December, 1974 to April, 1975. Further accuracy evaluations were not conducted after April 1975, but the scale was left in the roadway to see how well the installation would stand up to weather and traffic conditions. Periodic maintenance work was done on the scale until February 1976, when the scale assembly was removed from the roadway and placed in storage. The unit was inoperative when placed in storage.

3.6 Summary

There was considerable interest in weigh-in-motion systems in Canada. The desirability of having a system that could provide improved statistics related to axle weights and axle repetitions was generally recognized and was one of the primary motivating forces behind the interest in weigh-in-motion systems. It was generally viewed that these improved statistics would facilitate the evaluation and development of improved pavement design and management methods and could also be used to evaluate compliance with axle and vehicle weight regulations and assist in the development and evaluation of improved enforcement strategies.

Another primary motivating force for the interest in weigh-in-motion systems was the systems' potential application as a pre-screening device upstream from permanent weigh scale sites. It was generally felt that such a device could reduce the need to weigh trucks to only those near or exceeding the permitted limits, thus increasing the efficiency and potentially the effectiveness of enforcement programs while reducing the delays to the motor carrier industry.

The substantial investment involved in purchasing, installing and evaluating weigh-in-motion systems was limiting the magnitude of the effort that any individual agency could undertake. Further, while a number of agencies had tested a number of different weigh-in-motion systems, it was not clear as to which system, if any, was best suited for operation in the Canadian environment.

During informal discussions among individuals associated with the various weigh-in-motion projects across Canada, it became apparent that significant advantages existed for all concerned if a cooperative effort could be undertaken in the testing, evaluation and development of a weigh-in-motion system which would be suitable to the Canadian environment. In particular, a cooperative effort would increase the cost-effectiveness of allocated resources through the elimination of any duplication of effort between agencies. From these informal discussions, a project committee under the auspices of the Roads and Transportation Association of Canada emerged.

4. THE RTAC PROJECT COMMITTEE

4.1 Introduction

The RTAC Committee for Monitoring Vehicle and Axle Weights was formed and began its work in 1976. Membership consisted of representatives from the following:

1) Alberta Department of Transportation,
2) Saskatchewan Department of Highways and Transportation,
3) Ontario Ministry of Transportation and Communications,
4) Ministère des Transports du Québec,
5) New Brunswick Department of Transportation,
6) Transport Canada, Transportation Development Centre, and
7) University of Saskatchewan.

The overall objective of the RTAC Committee was to establish recommendations regarding equipment and procedures for programs monitoring axle and gross vehicle weights. This overall objective was translated into a specific program which was designed to evaluate available weigh-in-motion systems and make recommendations respecting their suitability to the Canadian environment. In initiating the program, a number of tasks were identified and defined by the members of the Project Committee, as were the roles and responsibilities of the various members of the Committee.

4.2 The RTAC Project

The initial task of the project was to field-test various types of weigh-in-motion scales. The four more promising weigh-in-motion systems selected for testing included the following:

1) The Viatec Axle Weight Analyzer,
2) The Texas Weigh-In-Motion System,
3) the University of Saskatchewan System, and
4) The Ontario Truck Axle Weight Sorter.

The Viatec System was to be tested by the Alberta Department of Transportation and the Ontario Ministry of Transportation and Communications, as they had some previous experience with this equipment. The New Brunswick Department of Transportation proposed to test the Texas System which they had used before. The Ontario Ministry was to also test the Truck Axle Weight Sorter. The University of Saskatchewan System was to be appraised in New Brunswick, Quebec, Ontario and Saskatchewan by the respective Departments of Transportation. Committee representatives from the University of Saskatchewan were to assist the agencies evaluating the University of Saskatchewan system wherever possible. Representatives of Transport Canada were to assist in the coordination of the project and participate in its overall evaluation.

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By the time the evaluation program was initiated, the Viatec System was no longer produced and replacement parts were no longer available. For this reason, the Viatec System was withdrawn from the evaluation.

The New Brunswick Department of Transportation, in initiating their efforts to evaluate the Texas System, assessed the condition of the scale installation site and the condition of the scale previously purchased.

The assessment of the installation site indicated that there had been a significant amount of deterioration of the highway surface at the site and upstream in the approach lane. This, coupled with the fact that the nearest static scale was now at a new location thirty kilometres away, made the original site unusable.

The assessment of the condition of the scale that had been previously purchased and that had been in the highway over two winters showed a considerable amount of damage and deterioration to the load cell chassis due to corrosive deicing salts. The scale unit would have required considerable cleaning, testing and replacement of parts to put it in operation again. In all, it was estimated that it would cost between $10,000 and $15,000 to repair and reinstall the scale at a new suitable site. Further, this installation would have been equipped with only an oscilloscope for obtaining, displaying and recording data. The basic data acquisition system that would be required to give results that could be meaningfully compared with other systems was found to cost about $35,000. The New Brunswick Department of Transportation estimated the total cost to obtain reliable results for the comparative evaluation of this system relative to others would be in the order of $50,000 to $70,000. This, combined with the previously demonstrated inability of the system to resist the intrusion of water and deicing salts resulted in the New Brunswick Department of Transportation recommending to the RTAC Committee that the Texas System be deleted from further evaluation. This recommendation was accepted by the Committee.

The Ontario Ministry of Transportation and Communications had in the interim undertaken testing and evaluation of the Truck Axle Weight Sorter which they had developed earlier. Difficulties associated with the instrumentation and analysis of the output from the six transducers, which were viewed as being insurmountable at reasonable cost, resulted in a decision by the Ministry to abandon the project.

The University of Saskatchewan, in cooperation with the Saskatchewan Department of Highways and Transportation, had pursued the testing and evaluation of the University of Saskatchewan system at the Clavet site. While some difficulties had been encountered with regard to the surface covering the scale platform and sealing the unit from moisture intrusion, the system was by-in-large operational and had been so for a period of up to two years.

As a result of the above developments, the University of Saskatchewan system remained as the one system to be evaluated in long-term field tests under the RTAC Project.

5. THE UNIVERSITY OF SASKATCHEWAN WEIGH-IN-MOTION SYSTEM

5.1 Introduction

At the initiation of the RTAC Project, the University of Saskatchewan system consisted of the scale assemblies that were installed in the roadway and an analog data acquisition system.

5.2 The Scale Assemblies

The University of Saskatchewan scale assemblies were designed and fabricated during the early stages of the project in the Engineering Shops at the University of Saskatchewan. The scale assemblies consist of five basic parts as illustrated in Figure 5.1 and utilize a mechanism which had been previously devised by Mr. George Dyck, Manager of Engineering Shops, for application in a static scale.

This mechanism, a unique feature of the scale, permits the realization of low friction, high rigidity, and the use of a single load cell, and results in only the vertical component of a force applied at any point on the load platform to be transmitted to the load cell.

As illustrated in Figure 5.1, the torque arms are arranged around the inner perimeter of the frame and are each held at the ends by a support assembly made up of four bearing blocks with a tool steel roller between each pair. The inner-most bearings transmit downward forces from the load platform to the torque arm; the outer-most bearings transmit an opposing upward force from the frame to the torque arms. To illustrate, consider Figure 5.2, which represents the two ends, A and B, of a single torque arm assembly.

If a downward force were applied to the load platform near end A, forces would be transmitted around the perimeter of the scale as follows:

1) The force on the platform would be transmitted through bearing #1 to the torque arm.
2) This downward force would be opposed equally by an upward force at bearing #2 by the frame.
3) The resulting couple would cause a torque on the torque arm, which would be transmitted down the arm to end B.
4) This torque would be transmitted back to the load platform through bearing #3 as a downward force equal to that at #1 which would be opposed by an upward force at bearing #4 exerted by the frame.
5) The load platform at end B would have the same downward force acting on it as at end A.
6) The force would then be transmitted to the adjacent end of the torque arm perpendicular to the one in question, where the process would be repeated.

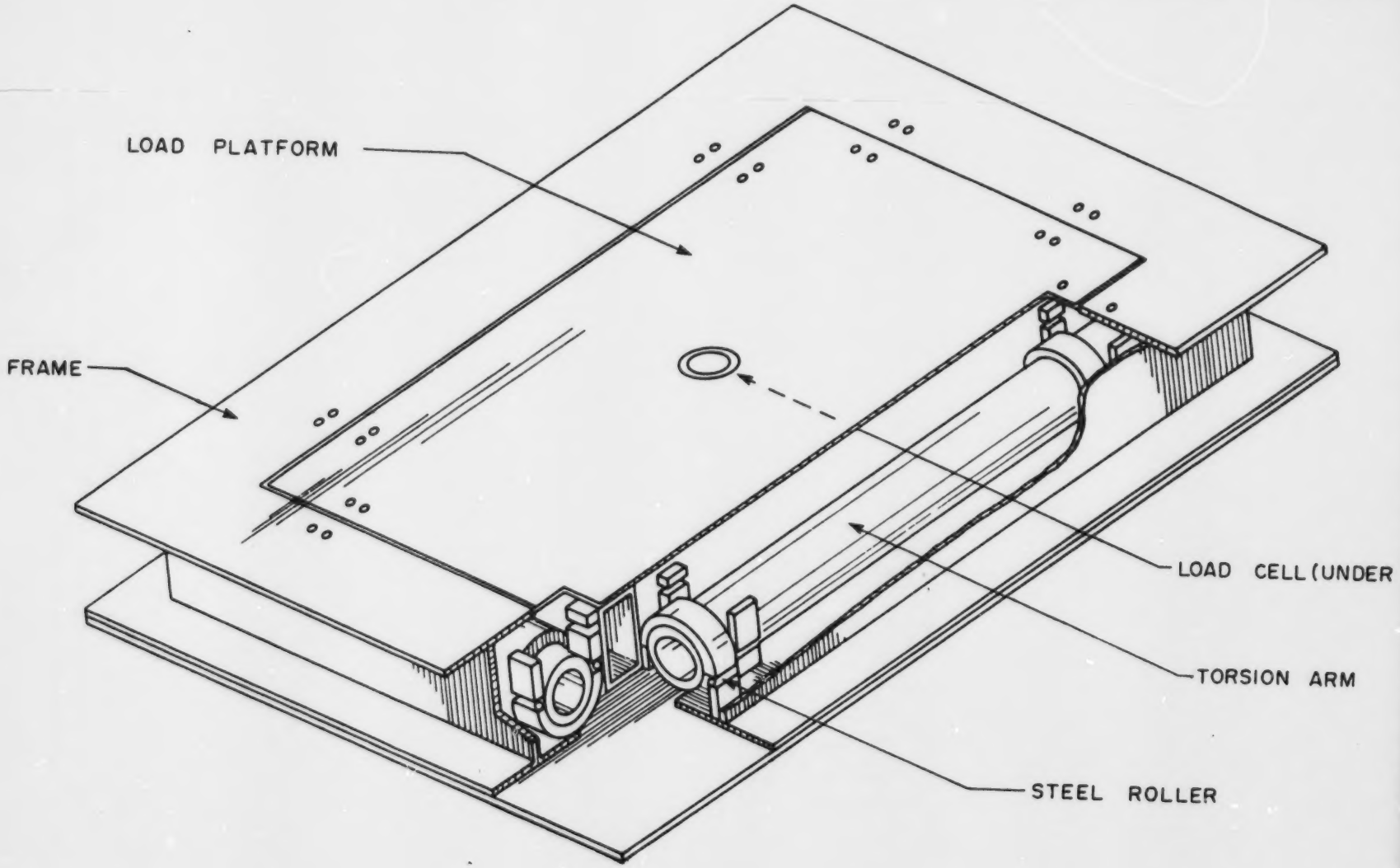


FIGURE 5.1

SCALE ASSEMBLIES

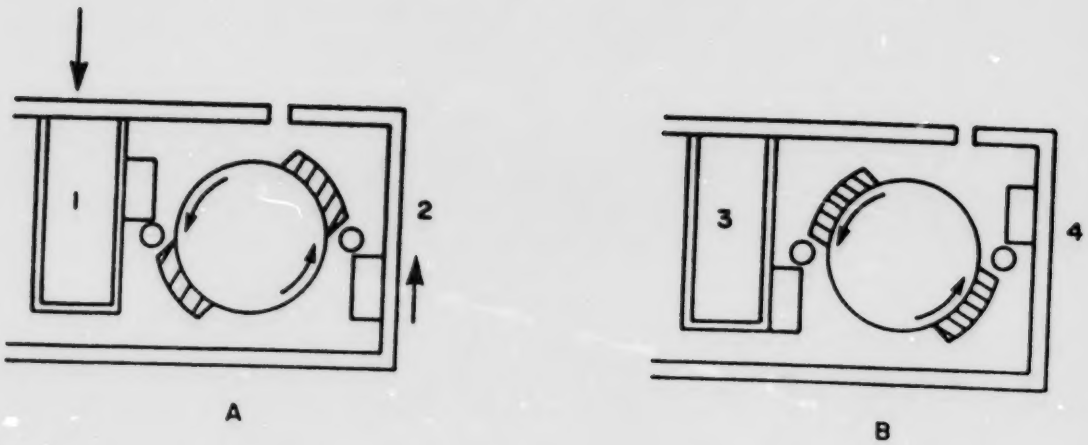


FIGURE 5.2

TORQUE ARM OPERATION

In this manner, a force on the load platform would be transmitted via the torque arms around the perimeter of the scale with the result that the downward deflection of the platform and hence the load cell, would be the same no matter where the load was applied on the platform.

The centrally-mounted hydraulic load cell is illustrated in Figure 5.3 and consists of a piston connected to the load platform through a ball and screw adjustment, a cylinder, and a transducer connected to the cylinder.

In order to achieve the lowest possible response time, the vertical travel of the load cell is as small as possible. This is accomplished by using a piston with a large surface area. This in turn allows the use of a flat diaphragm (as opposed to one with rolled or folded edges) between the face of the piston and the hydraulic fluid for purposes of sealing. For the 645 cm^2 piston-diaphragm arrangement used in the scale, a 13,600 kg load can be read by a 21 kg f/cm^2 transducer - the depth of the hydraulic fluid being about 0.125 mm and the piston motion at full load being about 0.025 mm. The photos in Figure 5.4 illustrate the scale assembly.

5.3 The Analog Data Acquisition System

In the very early stages of testing the University of Saskatchewan system, an oscilloscope and pen chart recorder were used as a data acquisition system. With the success of the initial tests in the abandoned section of roadway plus those at the site north of Saskatoon, it was deemed desirable to develop a data acquisition system which would be capable of recording the data associated with more than a few vehicles. In conjunction with the installation of the scale at the Clavet site in 1975, an analog data acquisition system was developed.

With this analog system the output of the transducers was recorded directly onto tape by an FM analog tape recorder. The analog tape was then taken to the University of Saskatchewan where it was processed by a hybrid analog-digital computer to produce a digital computer tape which in turn could be analyzed using the IBM 370 computer in the Central Computer Facilities at the University of Saskatchewan. This system, while being somewhat cumbersome and slow, served the purpose during the early testing at the Clavet site.

With the formation of the RTAC Project in 1976 and the proposed expanded testing and evaluation, it was necessary to develop a more sophisticated data acquisition system. This involved the development of an electronic interface, which included off-scale detectors and loop detectors, plus two on-site computer-based data acquisition systems.

5.4 The Electronic Interface

The electronic signals produced by the scale transducers, the off-scale detectors and the loop detectors required amplification and conditioning for input into the data acquisition system. This was accomplished by the Electronic Interface which was developed as part of the RTAC project. This interface is schematically illustrated in Figure 5.5.

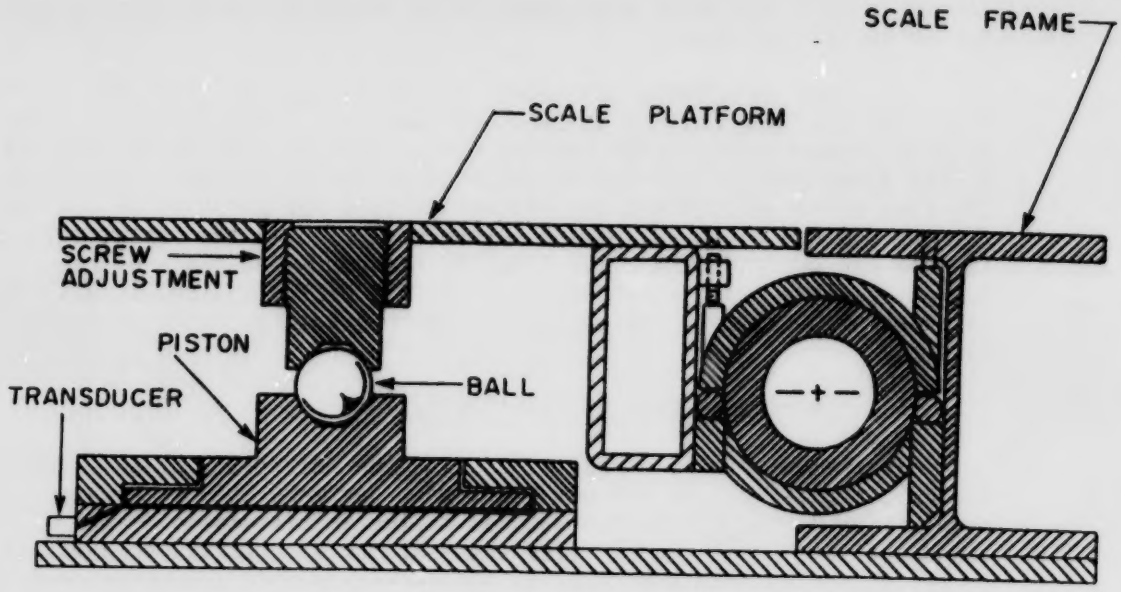
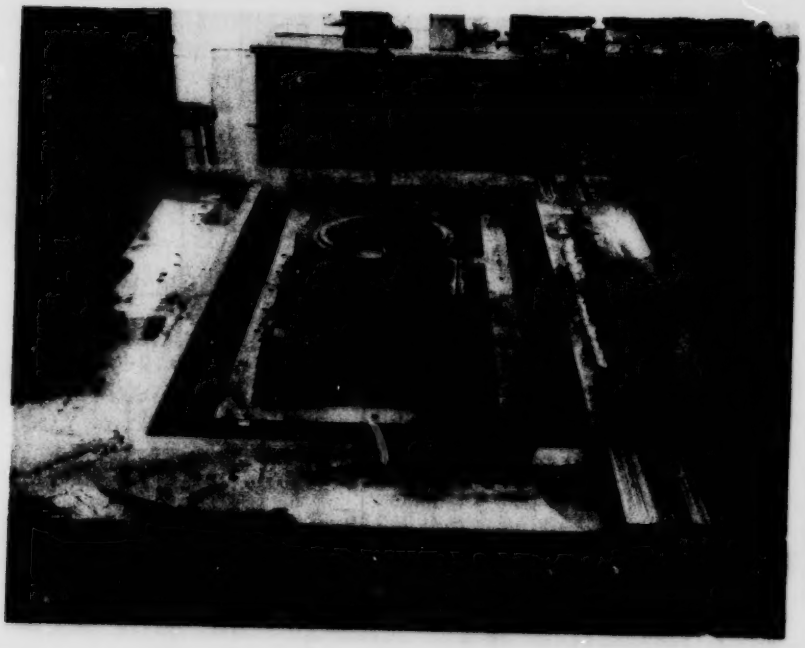


FIGURE 5.3

LOAD CELL ASSEMBLY

Scale Frame and Torsion Arms



Frame, Torsion Arms, Weighing Platform Frame and Load Cell

Figure 5.4
Scale Assembly

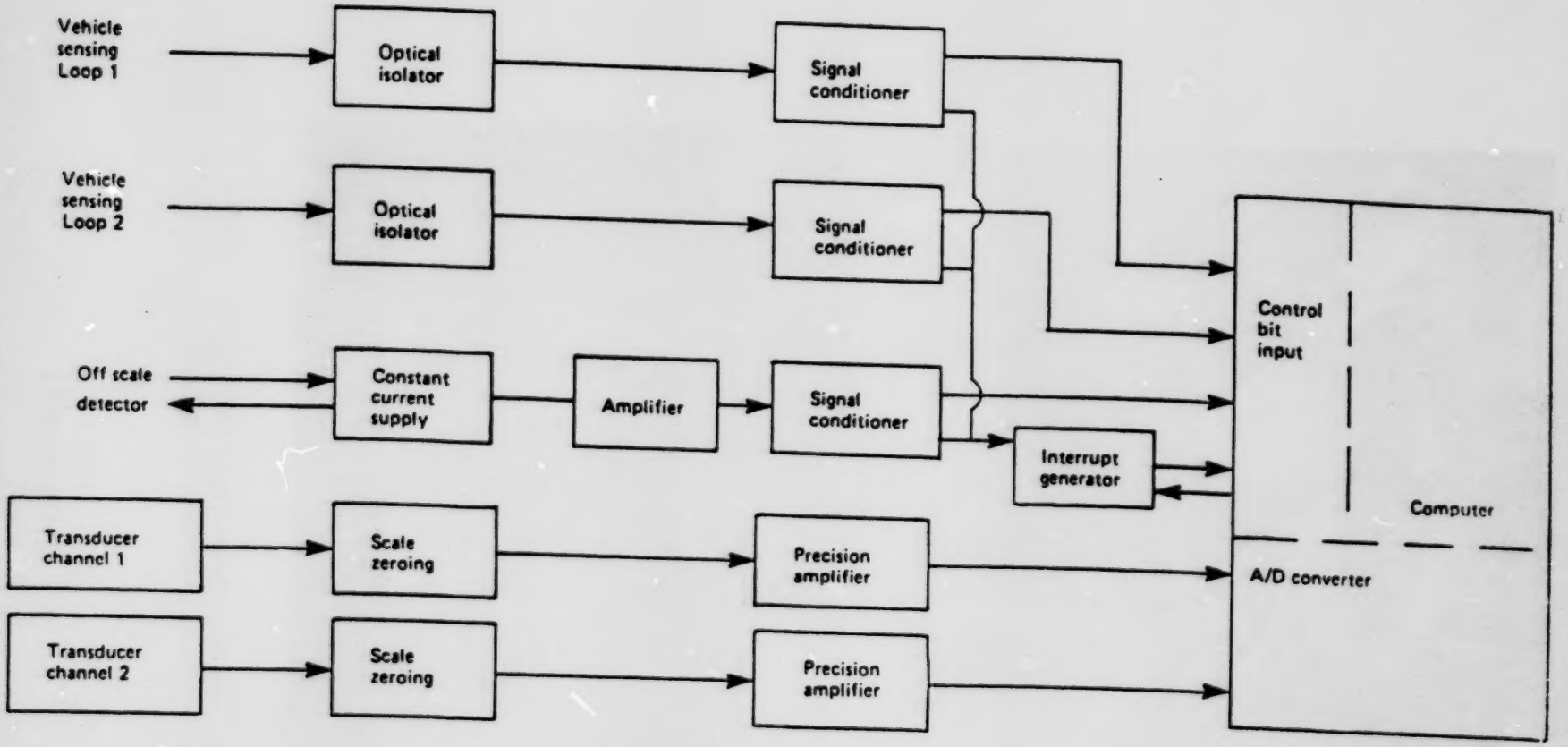


Figure 5.5

Block Schematics of Electronic Interface

The load cell transducers used were of the hydraulic pressure sensing type. The transducer's signals were amplified by a pair of precision instrumentation amplifiers up to a voltage which corresponded to the input range of the analog to digital converters which were used in the Digital Equipment Corporation computers utilized in the data acquisition system.

Vehicle entry and exit from the scale were detected by magnetic induction sensing loops buried in the pavement on either side of the scale. These loops were connected to standard "off-the-shelf" model magnetic sensing loop amplifiers similar to those used in traffic signal control. Output from the amplifiers acted as triggers for a set of semi-conductor switches connected to the computer and used by it to determine the presence of a vehicle in the system.

The off-scale detectors were four small strain gauge plates located at the outside edge of each scale. A wheel running over the plate generated a pulse which was amplified and sent to a one-shot switch which indicated to the computer that the vehicle was off the scale. The off-scale amplifiers and all of the switching circuitry were mounted on a single printed circuit board which could be removed and replaced with a spare in a matter of minutes.

A second circuit board held the parts of the time of day clock and the 1 kHz clock. The time of day clock produced the current time in a binary two-second count in a set of signals readable by the computer. The 1 kHz clock controlled the sampling rate of the analog to digital converter with one of the computers (the PDP 11/03).

These two circuit boards, the transducer amplifiers, the loop detector amplifiers, and the power supplies were all housed on a rack mounted slide box that fitted into the computer cabinet as illustrated in Figure 5.6.

5.5 Data Acquisition System

Two different yet similar data acquisition systems were developed as part of the RTAC Project. The two systems utilized Digital Equipment Corporation PDP 11/03 and PDP 11/04 computers as the basic component. The primary motivation for developing two systems was to provide flexibility related to cost in that the more sophisticated system which used the PDP 11/04 computer was rather expensive and offered many options, some of which were not required in all circumstances, whereas the system using the PDP 11/03 computer was relatively inexpensive, yet was not as versatile.

The PDP 11/03 micro-computer system is illustrated schematically in Figure 5.7. This unit has no mass storage device associated with it. Individual vehicle records were used immediately by the PDP 11/03 to update a set of stored summary tables after which the individual vehicle records were discarded. These tables were used to produce, on request, a set of reports on traffic statistics for the period since the last

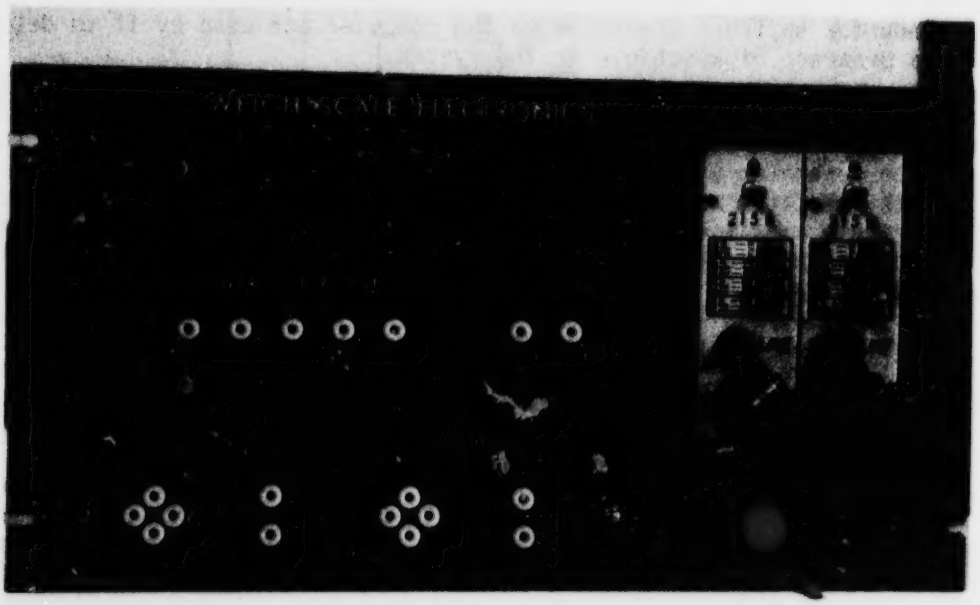


Figure 5.6

Weigh Scale Electronics

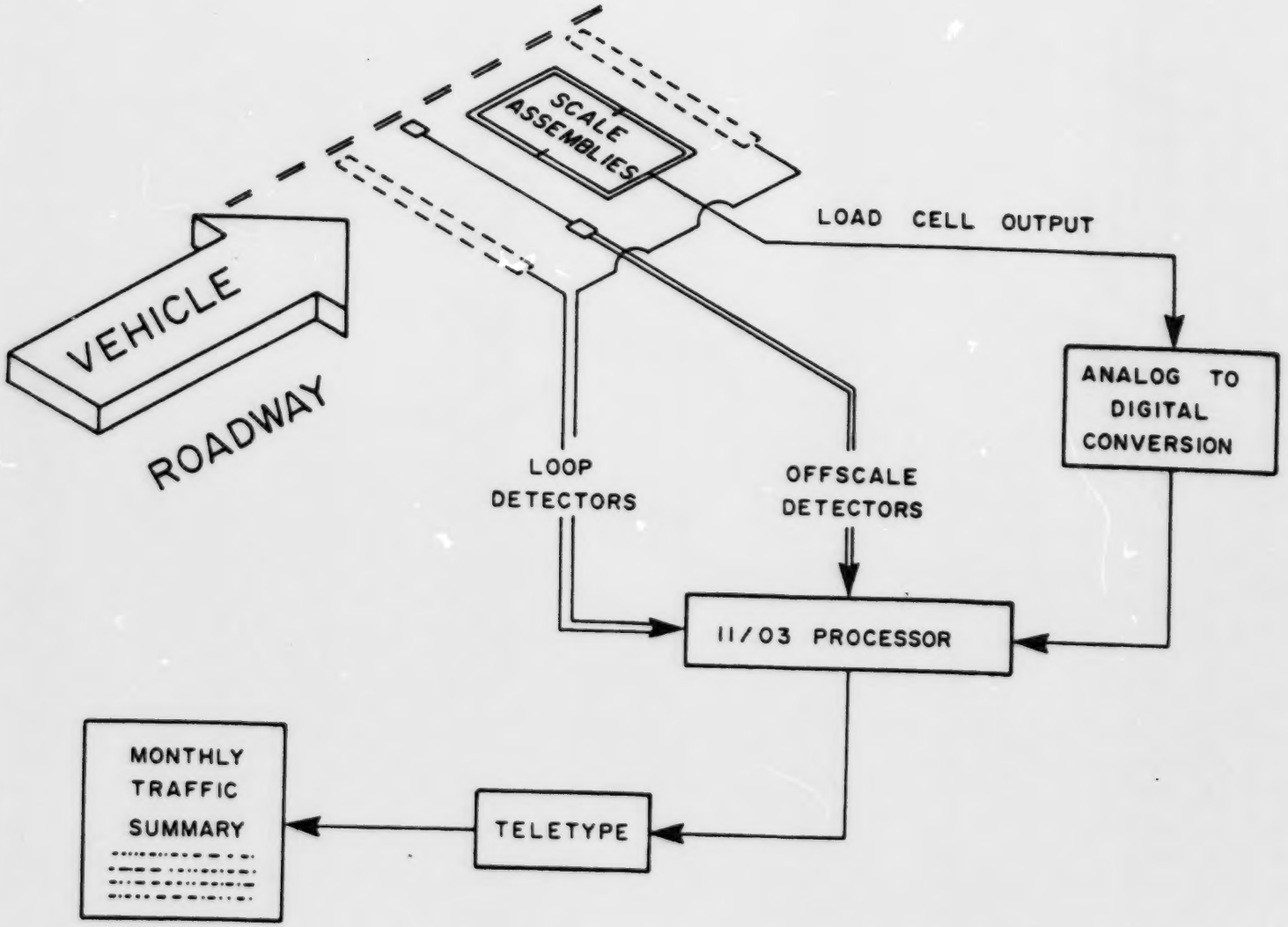


Figure 5.7

11/03 Data Acquisition System

report. Individual vehicle records could be printed out on the teletype if desired for test purposes. The PDP 11/03 system would have to be considered a basic data acquisition system in that it offered little in flexibility, but on the other hand, was not particularly expensive. This system was well suited for locations with low traffic volumes.

The PDP 11/04 system was substantially more sophisticated and offered considerable flexibility, but at the same time was considerably more expensive, primarily due to the peripheral equipment requirements. The PDP 11/04 system is schematically illustrated in Figure 5.8.

The PDP 11/04 was a somewhat more powerful machine than the PDP 11/03. The main difference was the availability of an industry standard tape drive and controller and an on-board programmable clock for controlling the sampling of the analog to digital converter.

While the PDP 11/03 system provided only a summary of traffic statistics, the PDP 11/04 system stored individual vehicle records on a magnetic tape which could then be analyzed on a central computer facility. Approximately 150,000 individual vehicle records could be stored on a single tape.

The PDP 11/03 system also had a cost advantage with regard to environmental requirements. The PDP 11/03 system required an operating temperature between 5^{o} C and 50^{o} C and humidity between 10% and 90%. A simple heater was sufficient to meet these needs. The environmental requirements of the PDP 11/04 system were fairly stringent, mainly to accommodate the tape unit. The acceptable temperature was between 15^{o} C and 32^{o} C and the relative humidity had to be between 20% and 80%. To meet these conditions, air conditioners, heaters and humidifiers were required.

Another significant difference between the two systems was that the semi-conductor memory of the PDP 11/03 was volatile; that is, its' contents were lost when not supplied with power. The PDP 11/04 system, on the other hand, had a nonvolatile memory. A battery backup system was included in the PDP 11/03 system to save the program and data in case of power failures of short duration.

The summary reports produced by the PDP 11/03 were subject only to the available storage in the computer. The manipulation of the individual vehicle records obtained from the PDP 11/04 system were only limited by the imagination of the analyst. Typical summaries as generated are included in Appendix A.

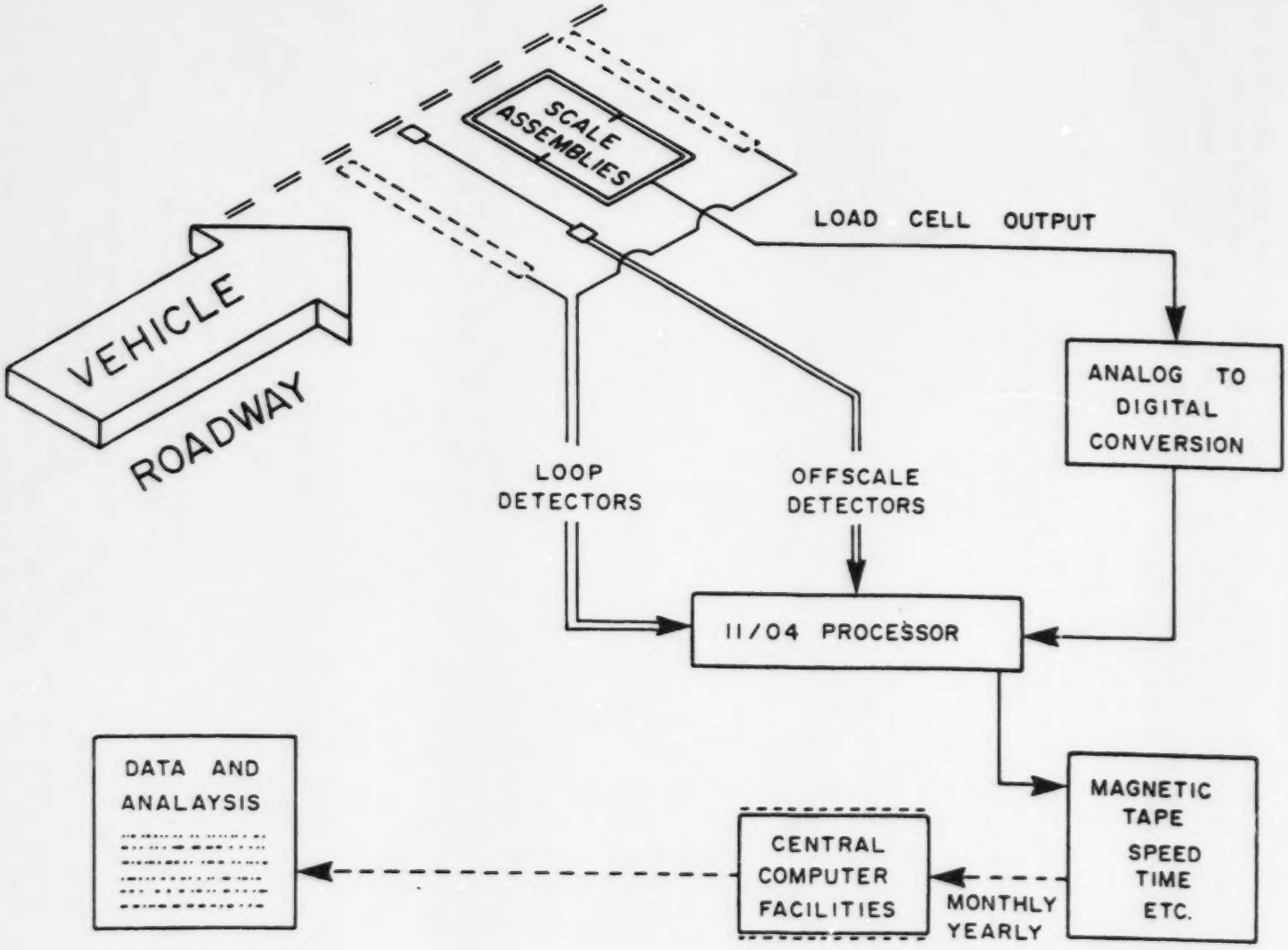


Figure 5.8

11/04 Data Acquisition System

5.6 Modifications to the Scale Assemblies

At the initiation of the RTAC Weigh-In-Motion Project, the scale assemblies used in the University of Saskatchewan system were at the stage of an operational prototype. During the course of the project, a number of minor design changes were made and one major redesign of the scale assemblies was completed.

The first scale assembly installed at Clavet in 1975 was paved over as it was thought that this might prove a satisfactory method of sealing the scales and providing a smooth surface over the scales. However, as is illustrated in Figure 5.9, problems were encountered with pavement breakup during cold weather.

Subsequent scales were, as illustrated in Figure 5.10, fitted with a cover made of a 6 mm rubber-fabric laminate bonded to the scales with high strength contact cement and held down at the edges by 6 mm x 50 mm steel bars screwed into the frame.

No problems were experienced with this arrangement in Saskatchewan, but as will be indicated in a later section of the report, these covers deteriorated under heavy traffic and were torn off by snow removal equipment at installations in Ontario, Quebec and New Brunswick. This allowed water to enter the scales and corrode the internal parts, with the major damage being to the transducers.

A subsequent proposed solution was to replace the covering with a top made of a neoprene mat vulcanized to either side of a 2 mm steel sheet and framed by a 5 mm x 25 mm steel grid. This modification, while being somewhat of an improvement, did not satisfactorily solve the problem and the intrusion of water into the scale assemblies persisted as one of the major unresolved problems.

The load cell piston used in the first scale was also changed slightly in later versions in order to extend the expected life. The first scale was in operation for three years and incurred approximately 1.5 million cycles before any degradation in accuracy due to piston binding occurred. This modification to the design of the piston was very successful in that no problems with the piston have been encountered since the modifications were implemented.

The scale assemblies themselves were also modified during the early stages of the project by increasing the width of the load platform from 1.42 metres to 1.72 metres. It had been indicated by a study carried out in Ontario in 1976 that this modification would reduce the number of vehicles missing the scale from about 20% to less than 5%.

As noted above, numerous design modifications were made to the scale assemblies during the early stages of the project. These modifications were followed by a major redesign of the scale assemblies with the installation of the first redesigned units at Clavet in the fall of 1978. This redesign incorporated several modifications which facilitated manufacture, installation and maintenance, and improved ruggedness.

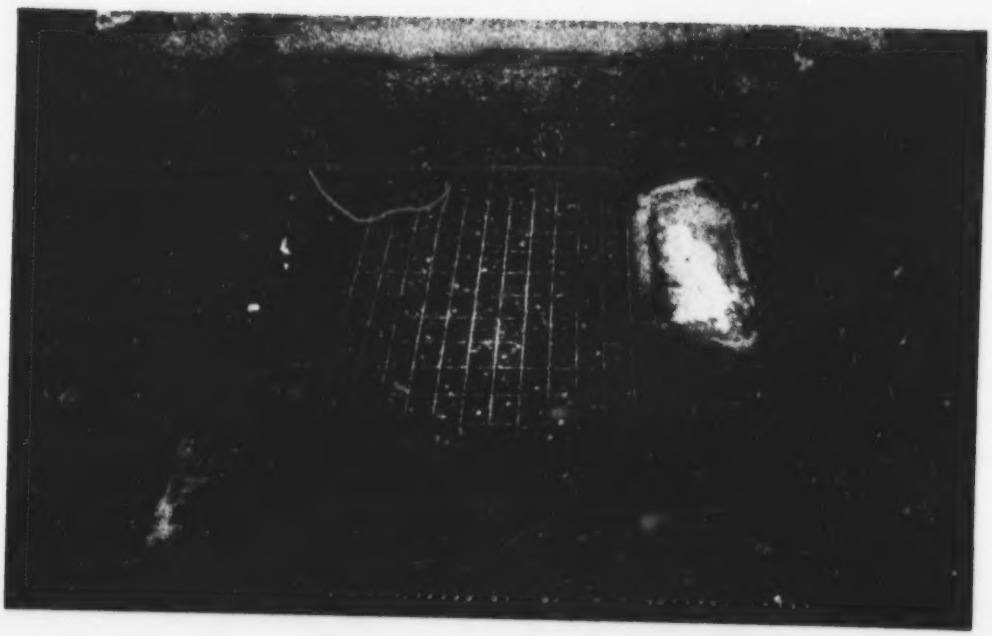


Figure 5.9

Clavet Scale Paved Over

Figure 5.10

Rubber Fabric on Weighing Platform

One modification involved the design of the torsion arms and the bearing pads. The first design incorporated hinge type connections between the torsion arms and the scale platform and scale frame. This system proved to have too much friction which adversely affected the accuracy. The redesigned system incorporated staggered pads and rollers in contact with the outside diameter of the torsion arms. While this system worked satisfactorily, it was difficult and expensive to manufacture and required 185 mm diameter torsion arms with 19 mm wall thicknesses. A subsequent redesign moved the bearing pads and rollers to the interior surface of the torsion arm, which reduced the difficulties associated with manufacture and reduced the required wall thickness of the torsion arms.

After the redesign, the major components of the scale were cast, as opposed to being fabricated from steel plates and beams, a procedure which required a great deal of cutting, welding and machining by highly skilled personnel. Casting allowed for greater sophistication to be built into the design. Further, the need for specialized skills and judgement were largely eliminated, thus reducing the man-hours required for fabrication by about 75%. The cast scale assemblies are illustrated in Figure 5.11.

The load cell was also redesigned so that it could be removed and installed in one piece through the top of the scale. The one piece construction, illustrated in Figure 5.12, made it much more resistant to moisture intrusion and the ability to remove it through the top of the scale greatly simplified replacement.

The early versions of the scale assemblies were installed in the roadway, as illustrated in Figure 5.13, by excavating a section of roadway, pouring a concrete pad, grouting and fastening the scale assemblies to the concrete pad, and backfilling around the scale with concrete. Needless to say, this was a major undertaking. Further, if the scale assemblies required service or repair, the whole process had to be repeated.

In order to facilitate installation and service, and also to provide some degree of portability to the scale assemblies, a system of frames and dummies was developed. As illustrated in Figure 5.14, the frames and dummies were installed in the roadway and then the scale assemblies were interchanged with the dummies as desired.

Cast Frame with Torsion Arms
Partially Installed

Cast Weighing Platform and Redesigned
Torsion Arms

Figure 5.11

Scale Assembly

Load Cell Removed Through the
Top of the Scale

Figure 5.12

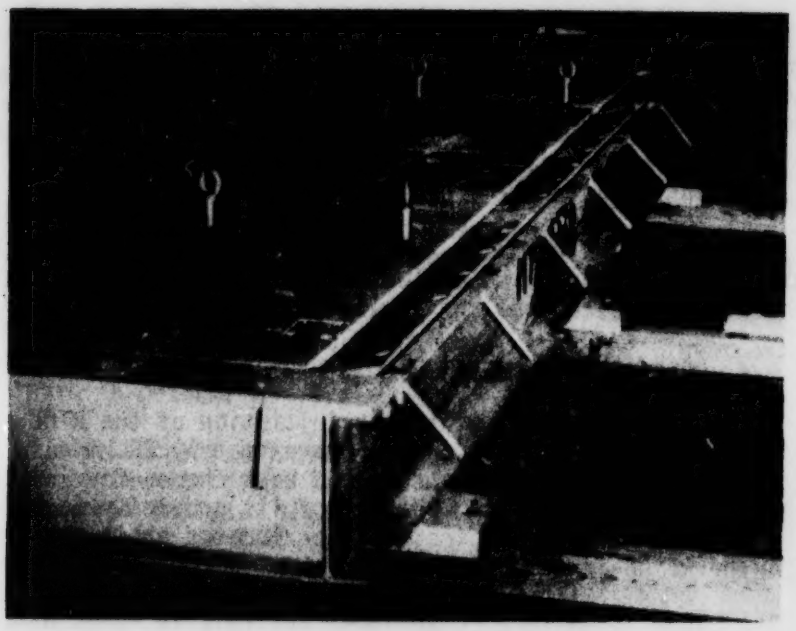
Load Cell

Excavation, Pad and Grout
Preparing for Scale Installation

Scale Ready to be Bolted in Place
and Backfilled with Concrete

Figure 5.13

Early Scale Installation Methods



Scale Frames with Dummy Plates

Installing Scales Into Frames

Figure 5.14

Frames and Dummies

6. INSTALLATIONS AND EXPERIENCE

6.1 Introduction

Under the RTAC Project, the University of Saskatchewan Weigh-In-Motion System was installed at two locations in Saskatchewan, and one in each of Ontario, Quebec and New Brunswick.

6.2 Saskatchewan Locations

As noted earlier, prior to the initiation of the RTAC project, scales had been installed at a site approximately 20 km east of Saskatoon, near the town of Clavet. This site had been chosen for initial testing of the weigh-in-motion system because of its proximity to both Saskatoon and a permanent weigh scale installation located about three kilometres east of the weigh-in-motion scale.

The Clavet site took on an important role in terms of testing equipment under the RTAC Project. Many of the scale assemblies that were eventually installed at other locations were field-tested at the Clavet site prior to shipment. Further, the electronic interface and the two data acquisition systems developed under the RTAC Project were field-tested at the Clavet site.

The Clavet location provided testing under continental climate conditions, with fairly light traffic conditions (an average daily total of 3000 vehicles in both directions consisting of approximately 12 percent trucks).

The first scale assembly installed at the Clavet site in late summer of 1975, prior to the initiation of the RTAC Project, was a single scale assembly installed in the outside wheel path in the eastbound lane. This assembly was paved over in the hope that such an approach would solve the moisture intrusion problems encountered earlier. Over the winter of 1975/76, the asphalt covering the scale broke up and was subsequently repaired in the spring of 1976. A second scale assembly was installed in the inside wheel path of the eastbound lane in May of 1976. This assembly was equipped with the rubber cover and was installed flush with the road surface. The scales at this site operated with an analog data acquisition system which had been developed earlier. In January, 1978, the first computer system, a PDP 11/04, was installed at Clavet and program testing began. By the spring of 1978, the system had been developed to the point where it was operational on a continuous, unmanned basis.

In late May, 1978, some of the electronics located at the Clavet site were damaged by a power surge. A number of thunder storms occurred just prior to the outage and lightning was suspected as the source, entering the circuitry via the signal lines from the scales. Damage was confined mainly to the signal conditioning printed circuit board. The damaged components were replaced and the system returned to operation in a few days. An overvoltage protection system was designed and installed.

Early in the summer of 1978, the pavement covering on the first scale assembly installed again began to deteriorate, resulting in a bump on the scale causing scale accuracy to diminish. It was repaved and a steel reinforcing grid was added.

In July of 1978, the load cell in the first scale assembly installed began to malfunction and was removed from service. A new redesigned load cell was installed and the system returned to operation.

Over the summer of 1978, testing of the PDP 11/03 system began and the PDP 11/04 system used to this point at the Clavet site was shipped to Quebec. The PDP 11/03 system became fully operational at the Clavet site in October of 1978.

In mid-September of 1978, a second set of scale assemblies were installed in the westbound lane at the Clavet site. One of these was of the new cast design. These were connected to the data acquisition system in December of 1978, enabling the evaluation of a multi-lane weigh-in-motion system. This system continued to operate at the Clavet site through the duration of the RTAC Project.

A weigh-in-motion system was installed at a second site in Saskatchewan in 1976. This site, illustrated in Figure 6.1, was in northern Saskatchewan near Montreal Lake on Highway #2 approximately 100 km north of Prince Albert. This particular installation is on a two-lane two-way roadway with an average daily traffic flow in the monitored lane of about 500 vehicles, 25% of which are trucks with most being logging trucks with gross vehicle weights between 30,000 kg and 64,000 kg on five axles. This scale is subjected to extremes of temperature (i.e. -40^{0} C) and loading.

The data acquisition package system for this installation utilized part of the original analog system developed prior to the initiation of the RTAC Project. This analog system, although being somewhat cumbersome to use and slow in throughput, has proved extremely reliable. The low traffic volumes allow three to four months of data to be stored on one tape.

This particular installation operated for three years with only minor problems. Some settling of the pavement in the approach to the scales occurred resulting in a marked decrease in scale accuracy. A minor pavement patching job restored the approach to its original profile and restored the initial scale accuracy. Also, the cable running from the scale to the trailer housing the electronics was cut once by a snowplow. In July of 1978, one transducer was replaced after showing signs of water damage. Other than these instances, operation at this site continued uninterrupted from start-up in 1976 through to 1979.

Figure 6.1

Montreal Lake Installation

6.3 Ontario Installation

Scale assemblies were installed in the fall of 1977 in the outside eastbound lane of Highway #401 at a location approximately 50 kilometres east of Toronto. This six-lane freeway handles in the order of 15,000 vehicles per day in the monitored lane with up to 40% trucks. This traffic, coupled with severe ice and snow removal problems (both salt and mechanical removal are utilized) made this site one of the most rigorous in terms of physical abuse and adverse environmental conditions.

Over the winter of 1977/78, the rubber cover was torn off the scale assemblies by a combination of heavy traffic and snow removal equipment. This enabled salt water to enter the scale assemblies and damage the transducers. Repairs were performed in the spring of 1978 by removing, cleaning and replacing the transducers in one scale assembly or site, and replacing the other scale assembly with a new unit shipped from Saskatchewan. (The corroded scale was cleaned up and returned to service at the Clavet site later in the year.)

The electronic interface and a PDP 11/04 data acquisition system were installed in March of 1978. Initial testing indicated that some of the electronics had been damaged in shipment. These were subsequently repaired.

Development of the software for the data acquisition system was carried out concurrently at the Clavet and Ontario sites over the spring and summer of 1978. Programs were written and tested in Saskatoon, then shipped to Ontario for testing on their system. This strategy of parallel development worked relatively well with the result that by early summer, 1978, the system was performing as designed.

The first data was read off a tape from the Ontario installation in June of 1978. One problem with the computer, related to the failure of the tape drive to restart properly after a power failure, necessitated more sophisticated restart electronics and some program changes in the associated program module.

A further problem was encountered with the software in reading the PDP 11/04 data tapes onto the IBM/DS 370 system. Several techniques were used in the PDP 11/04 program to permit a large amount of data to be stored on a relatively small amount of tape. In particular, variable record lengths, variable block lengths and binary encoding were used. Unfortunately, the IBM operating system does not support all of these more efficient data packing procedures with the result that approximately two months were required before a method of retrieving the data from the tape was developed. Following the preparation of the initial program, the staff of the Ontario Ministry of Transportation and Communications developed an assembly language program which did the job more efficiently.

Some roughness in the approach to the scales developed after their installation which resulted in large irregularities in the transducer output. These irregularities in the approach were corrected in July of 1978 using a mixture of sand and fast curing epoxy.

Figure 6.2

Ontario Installation

In July, 1978, the power supply and off-scale detector circuitry of the electronic interface were found to be burned out. The cause was a large power surge - likely a lightning strike on or near the scale site. The damaged components were replaced and the system was put back into operation with overvoltage protection and common grounding for all parts of the system.

In the fall of 1978, it was noticed that trailer axles of some flat deck tractor-trailer units were being missed or being registered as separate vehicles. This was related to the sensitivity of the magnetic loop detectors. The trailer body was high enough above the loops that they were turning off, indicating that the vehicle had passed from the scale even though the trailer was still over the scale. This difficulty was corrected by readjusting the sensitivity of the loop detectors.

6.4 Quebec Installation

Installation of the scale assemblies took place at the Quebec site in the fall of 1977. This installation was located on the Trans-Canada Highway, 16 kilometres east of Quebec City, and provided a test site with medium density traffic of about 6000 vehicles per day in the monitored lane. The highway at this location is a four-lane facility with approximately 20% trucks. This particular location was one of the more demanding in terms of total annual precipitation, which totalled 116 cm including 342 cm of snow.

The Quebec installation was somewhat different than the others in that the scale assemblies were located about 1250 metres upstream from a permanent weigh scale location and the data acquisition system was located at the site of the permanent scale. This was done to facilitate the possible use of the weigh-in-motion system as a pre-screening device for trucks entering the permanent weigh scale.

In order to send the signals from the transducers, loop detectors and off-scale detectors over the 1250 metre distance between the scale assemblies and the data acquisition system, special transmitting and receiving electronics were built for the system. Lines ran from the scales to a terminal box at the roadside, and then to a transmitter housing located near the edge of the roadway right of way. The transmitter housing was a heated enclosure 1.3 metres x 2 metres x 2.6 metres. Signals were transmitted via cable from the transmitter housing to the data acquisition system housed at the permanent weigh scale site.

Early in the winter of 1977/78, the rubber covers over the scale assemblies were torn off by snow removal equipment and were not repaired until the following spring. By spring, the scales were found to be full of salt water and extensively corroded. They were removed and shipped back to Saskatoon for repair. The structural members were found to be sound; however, the bearing surfaces and transducers required replacing. The scales were reinstalled later in the spring of 1978.

Some minor roadway roughness developed near the scale assemblies during the spring of 1978 and required repair. This was completed using sand and fast curing rubber epoxy.

In August of 1978, the electronics interface and the PDP 11/04 computer system which had been used at the Clavet site during initial program development and testing were shipped to Quebec. After some delays caused by the loss of the computer terminal during shipping, the system was installed and started up.

Approximately two weeks after start-up the system failed. Close inspection revealed all electronics in the transmitter housing were burned out with signs of heavy arcing inside the housing. Some of the receiver electronics were also damaged as were one pair of transmission wires. The source of the large power surge appeared to be either a lightning strike or a high voltage power line falling across the power lines to the scale. The electronics were repaired and a well-grounded lightning arrestor and overvoltage circuitry were installed.

Large differences in ground potential were also observed to build up and created a problem. It appeared as though these differences in ground potential were dependent upon varying soil and bedrock conditions. The addition of heavy gauge ground wires between all components alleviated this problem. Also, some electronic noise was being picked up by the transmission lines, possibly from a nearby radio station. This noise was successfully filtered out.

The terminal box located at roadside partially filled with water at one point during the summer, damaging one component. This appeared to result from a plugged drainage conduit.

Some difficulty was also experienced in reloading the program after a system outage. This was associated with a deficiency in the documentation and was rectified in due course.

6.5 New Brunswick Installation

Scale assemblies were installed approximately 40 kilometres west of Fredericton in Highway #2, a two-lane two-way highway with an average daily traffic in the monitored lane of 2500 vehicles, with about 20% trucks. This particular site presented a maritime environment with less extreme temperatures but high precipitation levels.

The scale assemblies were installed in the fall of 1977. Sometime during the first month of winter, the rubber covers were removed by snow removal equipment. They were replaced but were damaged again. Water intrusion caused corrosion and failure of the transducers. In the spring of 1978, the scales were removed, cleaned, and some new rollers and new transducers were installed on-site and the scales reinstalled.

In July, 1978, the PDP 11/03 computer and electronic interface were shipped from Saskatchewan to New Brunswick. When connected and

Figure 6.3

New Brunswick Installation

tested, the transducers were again found to be non-functional. Further testing indicated one to be water damaged and the other to have a faulty connecting wire. New transducers were installed and a test program was loaded and satisfactorily run.

In September of 1978, major damage to the electronics occurred again, apparently due to lightning. There was damage to the transducers, power supplies, amplifiers, and both circuit boards in the electronic interface. The electronics were repaired and reconnected at the end of October with the system made operational shortly thereafter.

6.6 Accuracy Tests

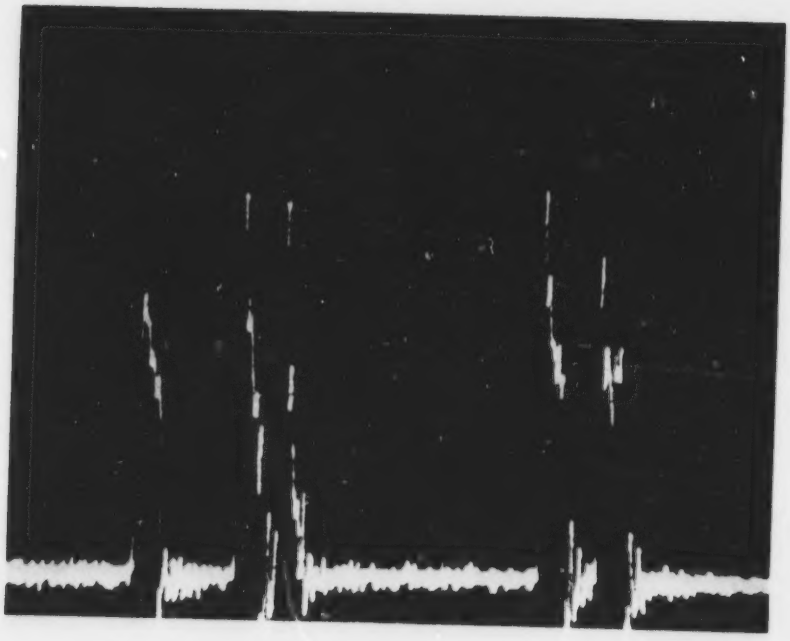
Numerous tests were undertaken during the development of the University of Saskatchewan weigh-in-motion system to assess its' accuracy. The tests usually involved either (1) a comparative analysis between static weights as determined by traditional platform scales with those as determined in motion by the weigh-in-motion system, or (2) repeatability tests using multiple determination of the in-motion weights of a test vehicle.

Without question, the single most important parameter relative to the accuracy of a weigh-in-motion system is smoothness of the approach roadway. This is aptly demonstrated by the transducer output traces illustrated in Figure 6.4 for before and after the repair of approach roadways.

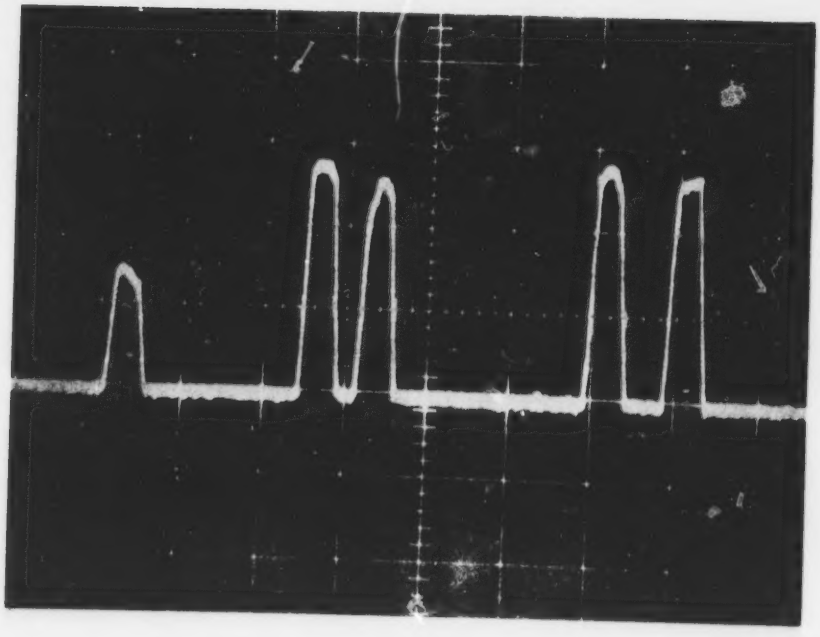
Table 6.1 summarizes the results of some repeatability tests performed in March of 1978 on the scales at the Clavet site. Figure 6.5 illustrates the data summarized in Table 6.1. From Figure 6.5, it is noted that there appears to be a tendency for axle weights to decrease somewhat as speed increases. It is suspected that this may be associated with aerodynamic uplift with increased speed. Also as illustrated in Figure 6.5, variability of axle weights tends to be highest for intermediate speeds. This is likely attributable to a combination of vehicle dynamics and time on the scale platform.

If the frequency distributions for the data in Table 6.1 are plotted as illustrated in Figure 6.6, and the observations are assumed to be normally distributed random variables, then it is possible to comment on the relative repeatability of the scale system.

From Table 6.1 and Figure 6.6, one can conclude that the weight of the front axle of the truck with an average weight of 3453 kg can be weighed in motion within 274 kg (8%) with 68% confidence (±1S) and within 548 kg (16%) with 95% confidence (±2S). Similarly, the weight of the rear tandem group and the gross vehicle weight can be determined within 420 kg (5%) and 577 kg (5%) with 68% confidence (±1S) and 840 kg (9%) and 1154 kg (9%) with 95% confidence (±2S) respectively.



Signals with Rough Approach



Signals After Approach Repaired

Figure 6.4

Transducer Output Traces

TABLE 6.1

REPEATABILITY TESTS
Clavet Site, March 3rd, 1978

Test Vehicle FORD F700

Speed (km/h)	Front Axle (kg)	Rear Axle (kg)	Total Vehicle (kg)
20	3557	8746	12,303
20	3570	9116	12,686
20	3480	8912	12,392
20	3417	9014	12,429
18	3672	9001	12,673
41	3608	8810	12,418
40	3633	9192	12,825
39	3646	9371	13,017
36	3366	9039	12,405
38	3417	9473	12,890
60	3531	9269	12,800
58	3468	8848	12,316
57	3455	8772	12,227
59	3404	9078	12,482
76	3264	8861	12,125
77	3264	8925	12,189
77	3327	8899	12,226
77	3251	8861	12,112
77	3289	8733	12,022
Average	3453	8990	12,450
Standard Deviation	137	210	288

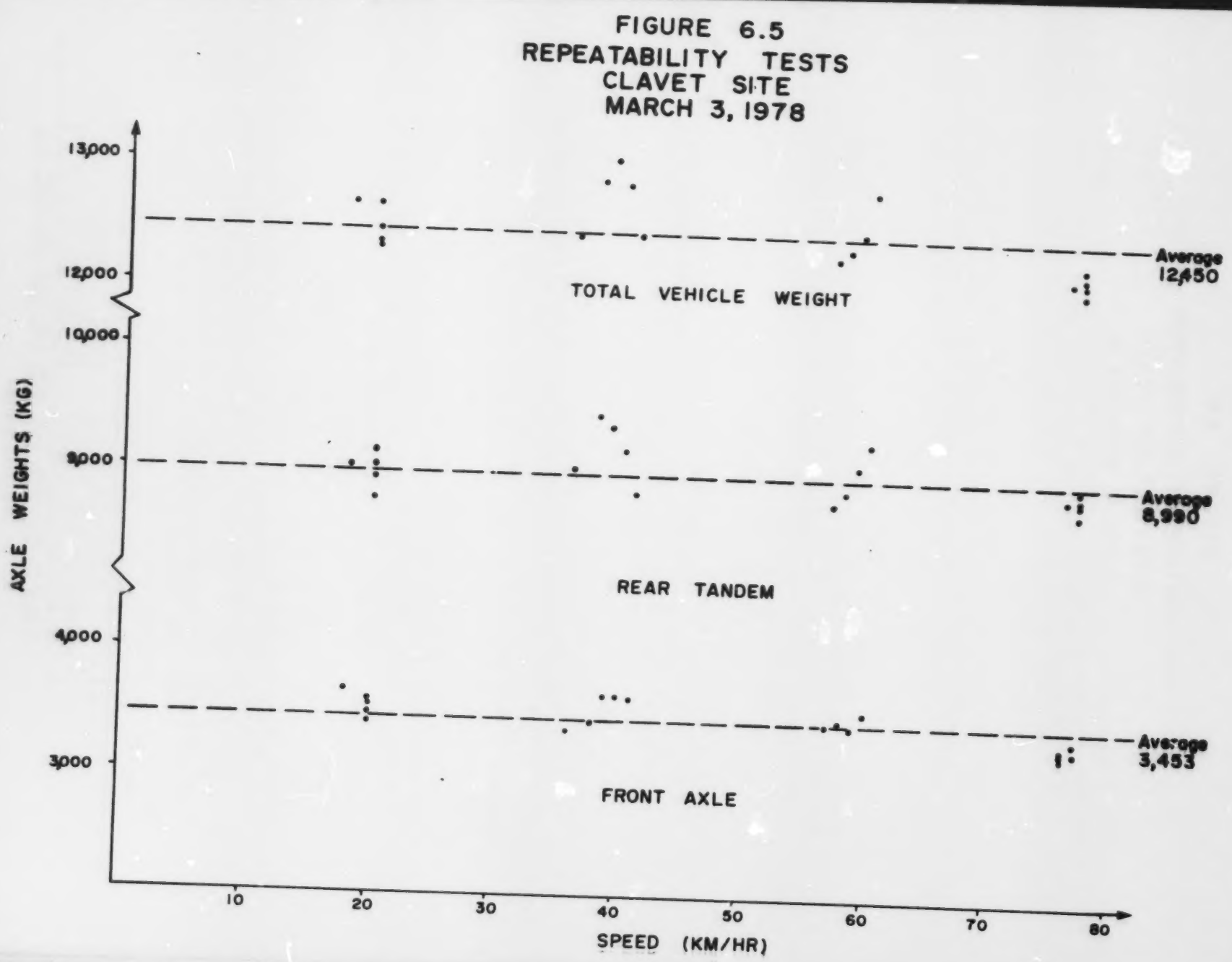
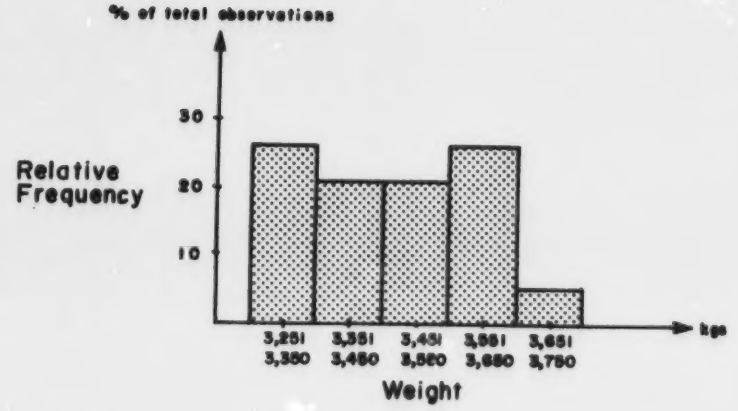
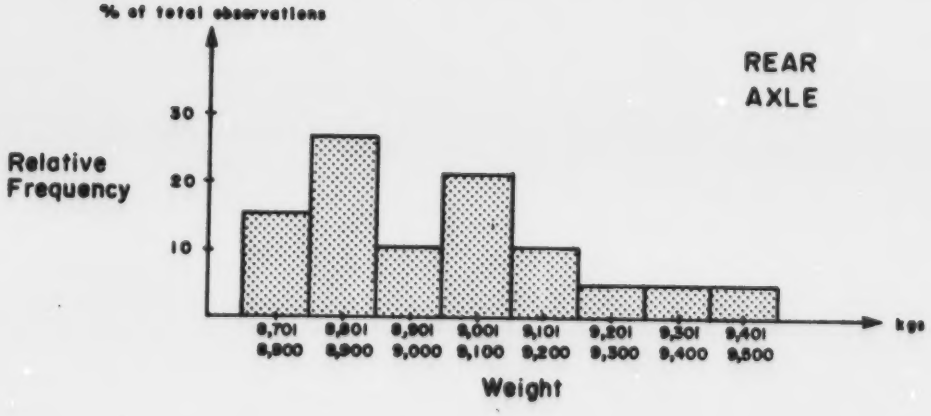


FIGURE 6.5
REPEATABILITY TESTS
CLAVET SITE
MARCH 3, 1978
AXLE WEIGHTS (KG)
13,000
12,000
10,000
8,000
4,000
3,000
TOTAL VEHICLE WEIGHT
Average 12,450
REAR TANDEM
Average 8,990
FRONT AXLE
Average 3,453
10
20
30
40
50
60
70
80
SPEED (KM/HR)

FIGURE 6.6
FREQUENCY DISTRIBUTIONS
REPEATABILITY TESTS
CLAVET MARCH, 1978





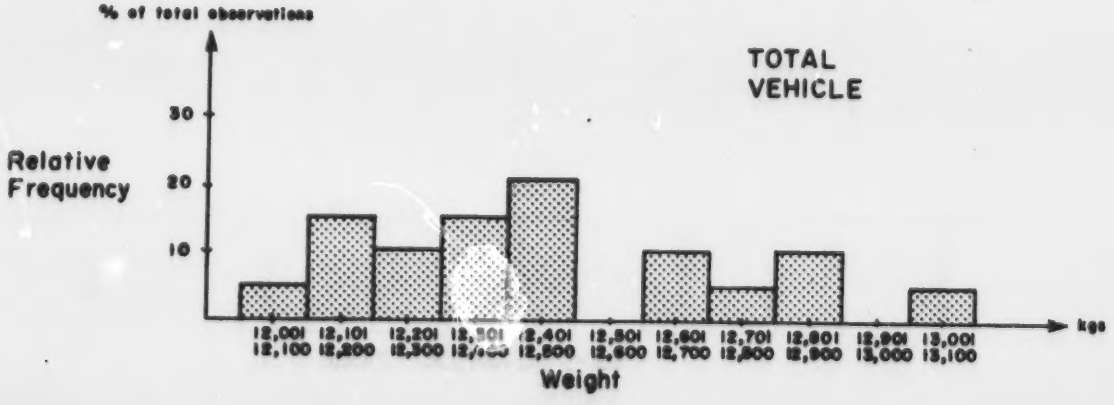


Table 6.2 summarizes the results of some repeatability tests performed on the slow roll-over installation at a chemical plant in Alberta in 1980. Again, if the frequency distributions are prepared as illustrated in Figure 6.7 and the observations are assumed to be normally distributed random variables, then one can conclude from the observations taken at slow but variable speeds that the weight of individual axles and gross vehicle weights can be determined within 1-2% with 68% confidence and within 2-3% with 95% confidence.

Similary, if the speeds are controlled (i.e. 3-5km/h), then one can conclude that the weights of individual axles and gross vehicle weights can be determined within 1% with 68% confidence and within 2% with 95% confidence.

In summary, it would appear as though one could expect to be able to determine the weight of individual axles and gross vehicle weights within 10% with 95% confidence at highway speeds and within 2% at controlled slow roll-over speeds using the University of Saskatchewan system. This compares favorably with results obtained using other weigh-in-motion systems.

6.7 Summary

When the RTAC Project was initiated in 1976, the University of Saskatchewan weigh-in-motion system was at the stage of having an operational prototype scale assembly and an analog data acquisition system, both of which had undergone some field-testing. These field tests had been completed under Saskatchewan conditions which included extreme temperatures, relatively low traffic volumes, and relatively low precipitation levels. As such, the environmental conditions to which the scales had been exposed were, in relative terms, favorable.

At the initiation of the RTAC Project, it was recognized that the weigh-in-motion system was in the early stages of development and a number of design improvements and the development of additional components were required. In particular, it was recognized that a better method of sealing the scale assemblies from moisture intrusion would have to be developed. This essentially translated into the need to develop a more durable cover which would withstand heavy traffic conditions. In addition, a complete data acquisition system which would be capable of handling large volumes of data would have to be developed to replace the somewhat archaic analog system initially used.

The units installed, tested and evaluated under the RTAC Project provided much needed input into the development process. The developments undertaken during the RTAC Project included:

1) modifications to the scale cover so as to increase its ability to withstand heavy traffic conditions,
2) redesign and modifications to the load cell to extend its service life and make removal of the load cell for service and repair through the top of the scale possible,

TABLE 6.2

REPEATABILITY TESTS
Fort Saskatchewan Site, June 27th, 1980

Run No.	Front Axle (kg)	First Tandem (kg)	Second Tandem (kg)	Total Vehicle (kg)
VARIABLE SLOW SPEED				
1	5160	7925	7829	20,914
2	5270	7894	7966	21,130
3	5232	7963	7853	21,048
4	5239	7863	7908	21,010
5	5204	7987	7839	21,030
6	5232	7860	7891	20,983
7	5177	7918	7771	20,866
8	5225	7836	7850	20,911
9	5197	7905	7784	20,886
10	5201	7826	7839	20,866
11	5163	7939	7805	20,907
12	5256	7874	7887	21,017
Average	5213	7899	7851	20,964
Standard Deviation	35	49	54	84
CONTROLLED SLOW SPEED (3-5 km/h)				
1	5246	7973	7891	21,110
2	5280	7915	7932	21,127
3	5273	7894	7922	21,089
4	5266	7994	7881	21,141
5	5280	7908	7925	21,113
6	5252	7994	7891	21,137
7	5259	7908	7929	21,096
8	5242	7994	7884	21,120
9	5276	7908	7932	21,116
10	5221	7980	7870	21,071
Average	5259	7946	7905	21,112
Standard Deviation	19	43	24	21

FIGURE 6.7
FREQUENCY DISTRIBUTIONS
FORT SASKATCHEWAN SITE
JUNE 27,1980

Variable Slow Speed

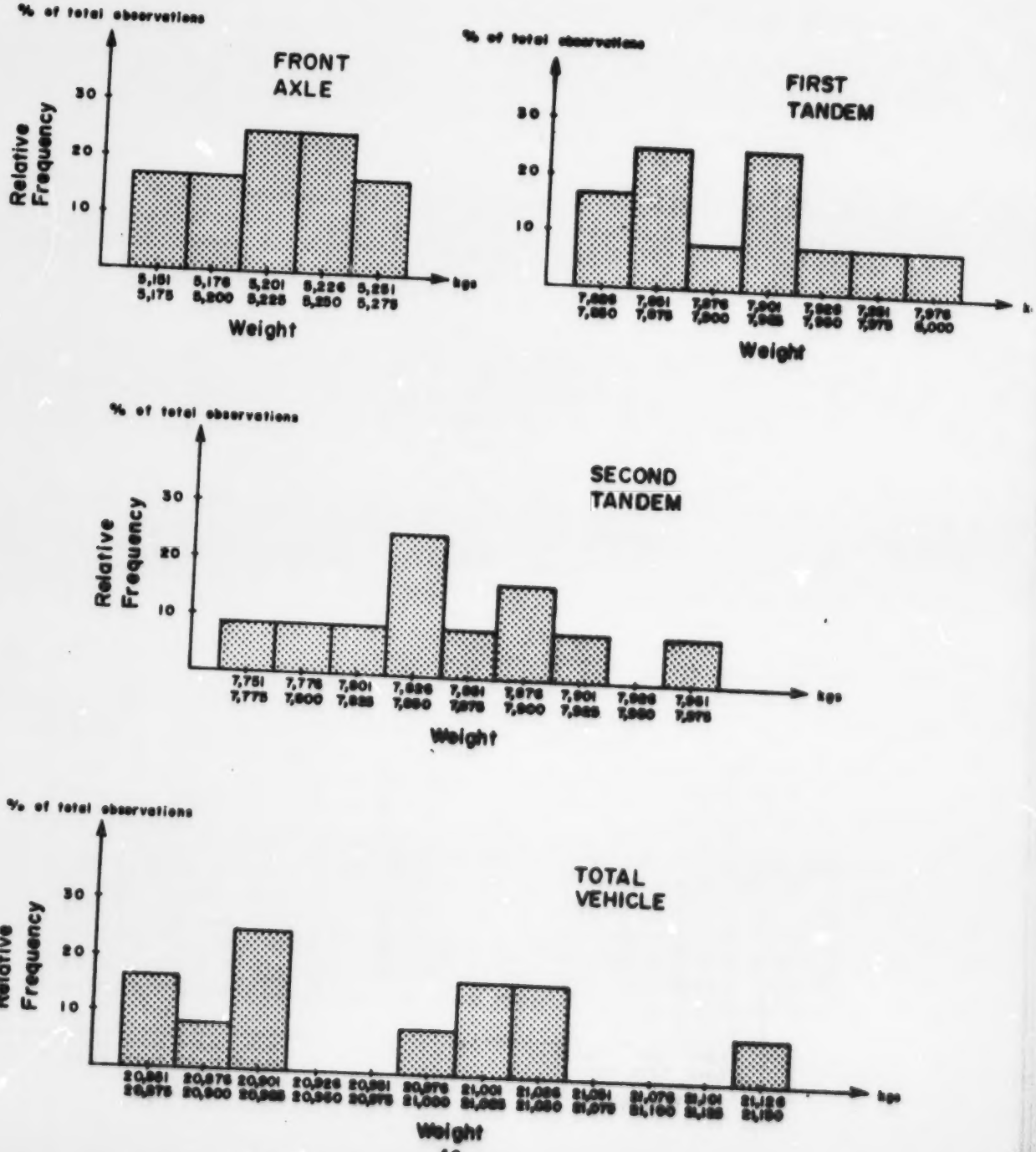
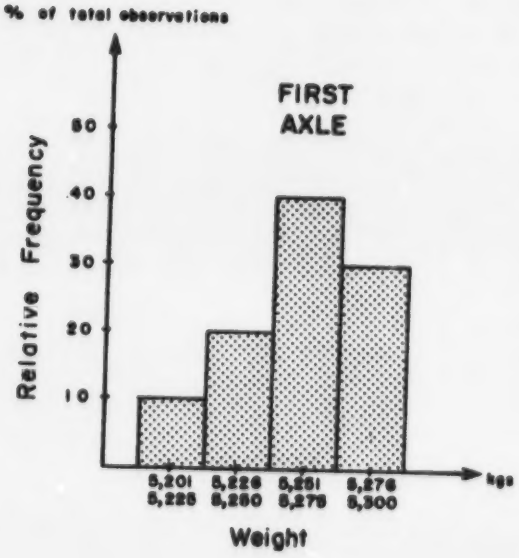
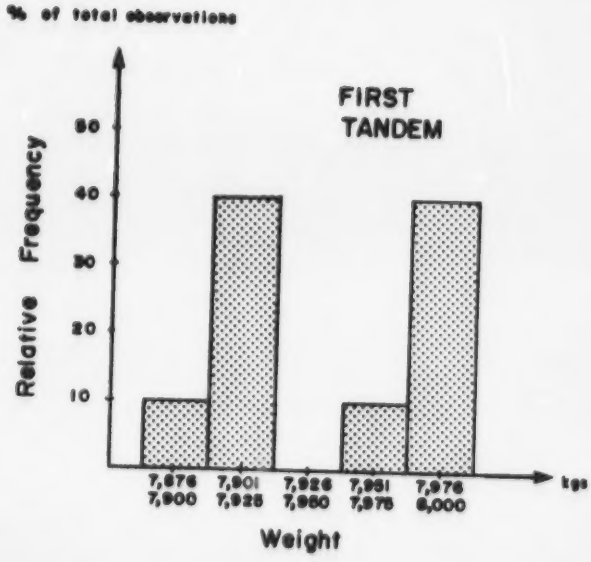
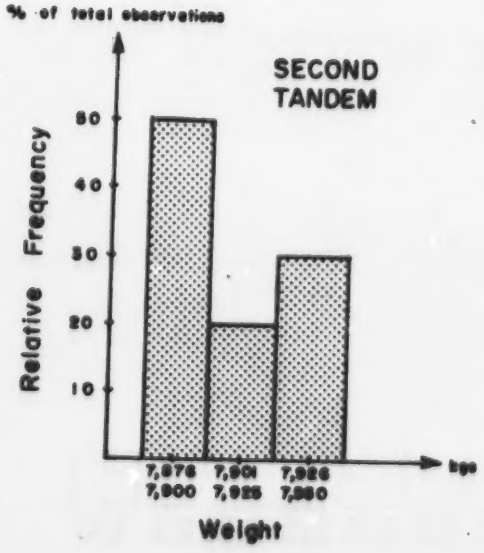


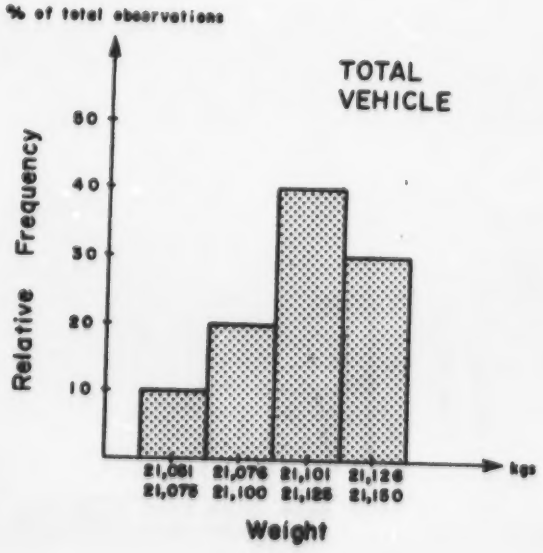
FIGURE 6.7
FREQUENCY DISTRIBUTIONS
FORT SASKATCHEWAN SITE
JUNE 27,1980

Controlled Slow Speed









3) the development of an electronic interface which included off-scale detectors and a vehicle detector system to control the data acquisition system,
4) the development of two data acquisition systems - one which was an economy model which provided summary tables of traffic statistics, and a second more sophisticated model which provided individual vehicle records which could be analyzed at a central computer facility,
5) a complete redesign of the scale assembly to increase its' ruggedness and durability,
6) modification in the manufacturing method used for the scale assemblies from fabricating to casting,
7) the development of a system of frames and dummies which facilitated installation of the scale assemblies and provided some degree of portability, and
8) the development of a system to control power surges from lightning or other sources.

At the conclusion of the RTAC Project in the fall of 1979, the systems located at Clavet and Montreal Lake in Saskatchewan were operational and had been so for the better part of a year. The system in Ontario was operational; however, the problems associated with maintaining a cover on the surface of the scale assemblies under heavy traffic conditions and thus the problem of water intrusion persisted. In addition, some bugs in the data acquisition system were creating difficulties. As such, the system was not operating trouble-free. The systems in Quebec and New Brunswick were operational; however, the problem of maintaining the cover on the scale assemblies also existed at these installations and as such, the systems at these locations could not be considered to be operating trouble-free.

6.8 Developments Since the RTAC Project

Further development, testing and evaluation of the University of Saskatchewan weigh-in-motion system has been undertaken since the completion of the RTAC Project. In particular, a new method has been developed to seal the scale assemblies, the off-scale detectors have been redesigned and an improved data acquisition system has been developed.

The problems with the cover on the scale and thus water intrusion appear to have been resolved by the new seal design. This design utilizes a seal in the joint between the scale platform and the scale frame. In this way the seal is not subjected to the wheel loads and the snow plow blades.

The redesigned off-scale detectors are now self-contained modules which utilize a magnetic sensor and are easily replaced compared to the original strain gauge design.

The new data acquisition system utilizes new hardware and a complete re-programming of the software package has been completed. This new system can be used as an on-site data acquisition system comparable to

the previous systems, or can be connected via telecommunications lines to a central facility. The telecommunications link eliminates the necessity of a field visit to collect data or to check on the operation of the system. This can now be done from a terminal located in any office with a telecommunications connection.

The Ontario Ministry of Transportation and Communications and the Saskatchewan Department of Highways and Transportation have continued weigh-in-motion programs. The Ministère des Transport du Québec and the New Brunswick Department of Transportation have at least temporarily discontinued their programs because of financial constraints.

In addition to the ongoing activities in Ontario and Saskatchewan, systems have been purchased and installed by the Minnesota State Highway Department, the Alberta Department of Transportation and a chemical manufacturing company located in Edmonton, Alberta.

The system in Minnesota is installed in Highway #I494 just west of the airport in Bloomington, Minnesota. Systems have been installed in two lanes at this particular site. The data acquisition system is on-site and does not have a telecommunications connection. The primary function of the installation is that of data collection for planning and design of highways.

The Ontario Ministry of Transportation and Communications have updated their system to include the new seals and the new data acquisition system complete with the telecommunications interconnection. In addition, a T.V. monitor system has been installed so the system can be used as a passive vehicle sorter in connection with the permanent weigh scale installation used for enforcement purposes located downstream about 1 km. The Ontario system is thus utilized for both data collection and as a sorter for the enforcement of axle and vehicle weights.

The Alberta Department of Transportation has installed three systems to date. Two are located in the two northbound lanes of Highway #2 just south of Edmonton near Leduc, Alberta. These are of the latest design and the data acquisition system includes the telecommunications interconnection. The third unit is located in the southbound lanes upstream of the permanent weigh scale located near Leduc, Alberta. This system is connected to an overhead sign as part of a sorter for the enforcement activities at the scale.

The system installed at the chemical plant in Edmonton is used as a slow roll-over system to check axle and gross vehicle weights of trucks prior to leaving the plant.

As of the fall of 1982, the systems in Saskatchewan, Ontario, Minnesota and Alberta were all operational. The new seal had performed satisfactorily at the sites in Ontario, Minnesota, and Alberta for periods upwards of one year.

7. SUMMARY AND CONCLUSIONS

7.1 Conclusions Resulting From the RTAC Project

1) The Viatec, Texas, and Ontario Truck Axle Weight Sorter systems are not appropriate for operation in the Canadian environment.

2) The University of Saskatchewan system has considerable potential for applications in the Canadian environment.

3) Further work related to the development of a more durable cover and system of sealing the scale assemblies is required for application under heavy traffic conditions and for installations subjected to intensive snow removal programs.

4) The interface and data acquisition systems developed during the RTAC Project can monitor traffic simultaneously in a number of lanes and can also handle traffic on a two-way roadway.

5) The system of frames and dummies developed facilitates the installation of scale assemblies into the roadway and provides a degree of portability to the units.

6) The problems encountered during the RTAC Project associated with power surges and lightning have been solved.

7) The University of Saskatchewan system is capable of determining axle and gross vehicle weights within 10% at highway speeds and within 2% at controlled slow roll-over speeds with 95% confidence.

7.2 Conclusions Resulting From Developments Since the RTAC Project

1) The problems associated with the cover on the scale assemblies and water intrusion appear to have been solved by the redesign which utilizes a seal in the joint between the scale frame and the scale platform.

2) The newly developed data acquisition system provides considerably more flexibility than previous designs in that it can operate as an on-site data acquisition system or can be connected via telecommunication links to central facilities.

3) The latest versions of the scale assemblies and the data acquisition system appear to be capable of operating on a continuous unmanned basis for extended periods.

4) The system appears appropriate for data collection at highway speeds, as a pre-screening device, and as a slow roll-over scale.

7.3 Future of the System

1) The system has reached a critical stage, in that an effective marketing, manufacturing, distribution and servicing system is now required to deliver the operational system to the consuming public.

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5. Much of the material in this section is based on an unedited Transport and Road Research Laboratory translation (Translation No. 2763) of "Auswahl geeigneter Radlastwiegevorrichtungen für Österreich" von Dipl.-Ing. Günter Breyer (The Selection of Suitable Weighing Equipment for Wheel Loads for Austria by G. Breyer).

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APPENDIX A

Typical Summaries
PDP 11/03
PDP 11/04

TOTAL TRUCKS OF THE GIVEN WEIGHT RANGES

WEIGHT RANGE	NUMBER OBSERVED THIS MONTH
5 – 10	221
10 – 15	189
15 – 20	86
20 – 25	88
25 – 30	127
30 – 35	70
35 – 40	54
40 – 45	36
45 – 50	38
50 – 55	35
55 – 60	26
60 – 65	41
65 – 70	87
70 – 75	82
75 – 80	32
80 – 85	1
85 – 90	0
90 – 95	1
95 – 100	1
100 – 105	2
105 – 110	1
110 – 115	0
115 – 120	0
120 – 125	0
125 – 130	0
130 – 135	0
135 – 140	0
140 – 145	0
145 – 150	0
150 – 155	0
155 – 160	0
160 – 165	0
165 – 170	0
170 – 175	0
175 – 180	0
180 – 185	0
185 – 190	0
190 – 195	0
195 – 200	0
200 – 205	0
205 – 210	0
210 – 215	0
215 – 220	0
220 – 225	0
225 – 230	0
230 – 235	0
235 – 240	0
240 – 245	0
245 – 250	0
250 – 255	0

WEIGH SCALE REPORTS – DATA TAKEN AT CLAVET SITE FROM MAR 16 TO MAR 31 77

TRAFFIC VOLUMES – BY CLASS AND TIME OF DAY FOR MONTH OF MARCH, 1977

TIME OF DAY		0 – 4	4 – 8	8 – 12	12 – 16	16 – 20	20 – 24	TOTALS
CLASS	VEHICLE TYPE							
1		390	1272	2444	3410	4089	1823	13428
2		2	7	22	25	19	7	82
3		4	2	8	18	17	5	82
4		0	0	1	2	3	0	6
5	2	9	20	159	160	111	35	494
6	3	2	12	18	17	10	9	68
7	2–S1	0	12	6	7	0	3	28
8	3–S1	0	0	2	0	0	1	3
9	2–S2	9	10	12	17	11	7	66
10	2–2	0	0	0	0	0	1	1
11	2–3	0	0	0	0	0	0	0
12	3–2	0	0	0	0	0	0	0
13	3–S2	56	88	88	93	79	89	493
14	2–S1–2	0	0	0	0	1	1	2
15	3–3	0	0	1	0	0	0	1
16	3–S1–2	0	3	1	2	3	1	10
17	3–S2–2	0	0	0	0	0	0	0
18	3–S2–2T	1	0	0	1	0	1	3
19	2–1	0	0	13	0	13	2	28
20	4	0	1	1	0	0	0	2
21	2–2T	0	0	0	0	0	0	0
22	3–S3	0	0	0	0	0	0	0
23	3–3T	0	0	0	0	0	0	0
24	2–S3	0	0	0	0	0	0	0
25	2–3T	0	0	0	0	0	0	0
26	OTHERS	1	6	4	4	5	3	23
TOTALS		474	1433	2780	3756	4361	1988	14792

WEIGH SCALE REPORTS – DATA TAKEN AT CLAVET SITE FROM MAR 16 TO MAR 31 77

AVERAGE VEHICLE SPEEDS (IN MPH) – BY CLASS AND TIME OF DAY FOR MONTH OF MARCH, 1977

TIME OF DAY		0 – 4	4 – 8	8 – 12	12 – 16	16 – 20	20 – 24	AVG SPEED
VEHICLE CLASS	TYPE							
1		61	64	63	64	63	60	63
2		60	59	57	58	59	55	58
3		55	43	55	60	55	52	56
4		0	0	47	54	58	0	55
5	2	60	59	56	58	61	59	58
6	3	55	58	54	56	57	54	56
7	2–S1	0	52	50	48	0	54	51
8	3–S1	0	0	47	0	0	48	47
9	2–S2	55	54	57	59	58	59	57
10	2–2	0	0	0	0	0	56	56
11	2–3	0	0	0	0	0	0	0
12	3–2	0	0	0	0	0	0	0
13	3–S2	53	53	54	56	55	53	54
14	2–S1–2	0	0	0	0	66	53	59
15	3–3	0	0	55	0	0	0	55
16	3–S1–2	0	55	57	55	50	59	54
17	3–S2–2	0	0	0	0	0	0	0
18	3–S2–2T	35	0	0	61	0	50	48
19	2–1	0	0	65	0	65	65	65
20	4	0	60	30	0	0	0	45
21	2–2T	0	0	0	0	0	0	0
22	3–S3	0	0	0	0	0	0	0
23	3–3T	0	0	0	0	0	0	0
24	2–S3	0	0	0	0	0	0	0
25	2–3T	0	0	0	0	0	0	0
26	OTHERS	52	50	55	63	53	63	56
AVG SPEED		59	63	62	63	63	60	61

WEIGH SCALE REPORTS – DATA TAKEN AT CLAVET SITE FROM MAR 16 TO MAR 31 1977

TRUCK AXLE VOLUMES – BY WEIGHT (IN KIPS) AND TYPE FOR MONTH OF MARCH, 1977

FRONT AXLES		SINGLE AXLES		TANDEM AXLES		TRIPLE AXLES	
WEIGHT RANGE	VOLUME	WEIGHT RANGE	VOLUME	WEIGHT RANGE	VOLUME	WEIGHT RANGE	VOLUME
3 – 6	505	0 – 12	552	0 – 24	584	0 – 18	0
6 – 8	288	12 – 14	45	24 – 26	59	18 – 24	0
8 – 10	357	14 – 16	49	26 – 28	76	24 – 30	0
10 – 12	40	16 – 18	51	28 – 30	122	30 – 36	0
12 – 14	5	18 – 20	19	30 – 32	139	36 – 42	0
14 – 16	3	20 – 22	1	32 – 34	108	42 – 48	0
16 +	1	22 – 24	0	34 – 36	49	48 – 54	0
TOTAL	1199	24 – 26	0	36 – 38	9	54 – 60	0
		26 +	0	38 – 40	2	60 – 66	0
		TOTAL	717	40 – 42	0	66 – 72	0
				42 – 44	0	72 – 78	0
				44 – 46	0	78 – 84	0
				46 – 48	0	84 – 90	0
				48 – 50	0	90 – 96	0
				50 – 52	0	96 – 102	0
				52 – 54	0	102 – 108	0
				54 – 56	0	108 – 114	0
				56 – 58	0	114 – 120	0
				58 – 60	0	120 – 126	0
				60 – 62	0	126 – 132	0
				62 – 64	0	132 – 138	0
				64 – 66	0		0
				66 – 68	0		0
				68 – 70	0		0
				70 – 72	0		0
				72 – 74	0		0
				74 – 76	0		0
				76 +	0		0
				TOTAL	1148		

NOTE A WEIGHT RANGE GIVEN ABOVE AS 14 – 16, FOR EXAMPLE, ACTUALLY COVERS THE RANGE 14.001 – 16.000 ETC.

WEIGH SCALE REPORTS – DATA TAKEN AT CLAVET SITE FROM MAR 16 TO MAR 31 77

TRUCK VOLUMES – BY HOUR OF DAY AND DAY OF WEEK FOR MONTH OF MARCH, 1977

DAY OF WEEK	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SUB-TOTAL	SATURDAY	SUNDAY	TOTAL
TIME OF DAY									
0.00 – 1.00	4	2	1	0	10	17	2	6	25
1.00 – 2.00	4	2	0	0	3	9	2	9	20
2.00 – 3.00	4	3	0	1	7	15	1	2	18
3.00 – 4.00	2	3	0	2	1	8	4	3	15
4.00 – 5.00	3	3	0	2	9	17	7	4	28
5.00 – 6.00	5	3	0	3	10	21	7	6	34
6.00 – 7.00	4	7	0	1	15	27	6	7	40
7.00 – 8.00	4	7	[illegible]	3	17	32	13	5	50
8.00 – 9.00	13	17	[illegible]	11	41	84	31	18	133
9.00 – 10.00	8	13	4	4	14	43	6	10	59
10.00 – 11.00	8	11	6	4	12	41	7	6	54
11.00 – 12.00	7	9	9	2	13	[illegible]	10	9	59
12.00 – 13.00	8	3	11	4	15	41	13	11	65
13.00 – 14.00	9	1	16	7	19	52	13	14	79
14.00 – 15.00	11	6	4	7	18	46	14	8	68
15.00 – 16.00	6	5	2	21	29	63	19	7	89
16.00 – 17.00	3	0	2	12	14	31	4	11	46
17.00 – 18.00	7	3	2	10	15	37	11	11	59
18.00 – 19.00	5	4	2	19	16	46	14	8	68
19.00 – 20.00	9	4	1	12	14	40	17	3	60
20.00 – 21.00	4	2	2	13	18	39	11	6	56
21.00 – 22.00	5	0	0	15	14	34	5	3	42
22.00 – 23.00	7	1	1	2	7	18	1	5	25
23.00 – 24.00	4	2	0	10	8	24	3	3	30
TOT TRAFFIC VOL	144	111	66	165	339	825	222	175	1222
DAYS IN MONTH	2	2	3	3	2		2	2	

WEIGH SCALE REPORTS – DATA TAKEN AT CLAVET SITE FROM MAR 18 TO MAR 31 77

TRUCK EQUIVALENCY FACTORS – FOR MONTH OF MARCH, 1977

OBSERVATION PERIOD	TRUCK POPULATION	EQUIVALENCY	EQUIV./1000 TRUCKS
WHOLE MONTH	1169	825.7	706.3
7 DAYS (MON–SUN)	544	375.4	690.1
5 DAYS (MON–FRI)	330	237.9	720.9

EQUIVALENCIES AS DETERMINED BY SAMPLING THOSE TRUCKS TRAVELLING BETWEEN 8 A.M. AND 8 P.M. ON WEEDKAYS

SAMPLE SIZE REQUIRED	SAMPLE SIZE OBTAINED	EQUIVALENCY	EQUIV./1000 TRUCKS
100 TRUCKS	100	46.7	466.6
200 TRUCKS	200	81.6	408.1
300 TRUCKS	300	147.0	490.0
500 TRUCKS	500	266.5	533.0
1000 TRUCKS	555	294.0	529.8

WEIGH SCALE REPORTS – DATA TAKEN AT CLAVET SITE FROM MAR 16 TO MAR 31 77

AVERAGE HOURLY TRUCK VOLUMES – BY HOUR OF DAY AND DAY OF WEEK FOR MONTH OF MARCH, 1977

DAY OF WEEK	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	MON–FRI AVG	SATURDAY	SUNDAY	MON–SUN AVG
TIME OF DAY									
0.00 – 1.00	2.0	1.0	0.3	0.0	5.0	1.4	1.0	3.0	1.0
1.00 – 2.00	2.0	1.0	0.0	0.0	1.5	0.8	1.0	4.5	1.3
2.00 – 3.00	2.0	1.5	0.0	0.3	3.5	1.3	0.5	1.0	1.1
3.00 – 4.00	1.0	1.5	0.0	0.7	0.5	0.7	2.0	1.5	0.9
4.00 – 5.00	1.5	1.5	0.0	0.7	4.5	1.4	3.5	2.0	1.8
5.00 – 6.00	2.5	1.5	0.0	1.0	5.0	1.8	3.5	3.0	2.1
6.00 – 7.00	2.00	3.5	0.0	0.3	7.5	2.3	3.0	3.5	2.5
7.00 – 8.00	2.0	3.5	0.3	1.0	8.5	2.7	6.5	2.5	3.1
8.00 – 9.00	6.5	8.5	0.7	3.7	20.5	7.0	15.5	9.0	8.3
9.00 – 10.00	4.0	6.5	1.3	1.3	7.0	3.6	3.0	5.0	3.7
10.00 – 11.00	4.0	5.5	2.0	1.3	6.0	3.4	3.5	3.0	3.4
11.00 – 12.00	3.5	4.5	3.0	0.7	6.5	3.3	5.0	4.5	3.7
12.00 – 13.00	4.0	1.5	3.7	1.3	7.5	3.4	6.5	5.5	4.1
13.00 – 14.00	4.5	0.5	5.3	2.3	9.5	4.3	6.5	7.0	4.9
14.00 – 15.00	5.5	3.0	1.3	2.3	9.0	3.8	7.0	4.0	4.3
15.00 – 16.00	3.0	2.5	0.7	7.0	14.5	5.3	9.5	3.5	5.0
16.00 – 17.00	1.5	0.0	0.7	4.0	7.0	2.6	2.0	5.5	2.9
17.00 – 18.00	3.5	1.5	0.7	3.3	7.5	3.1	5.5	5.5	3.7
18.00 – 19.00	2.5	2.0	0.7	6.3	8.0	3.8	7.0	4.0	4.3
19.00 – 20.00	4.5	2.0	0.3	4.0	7.0	3.3	8.5	1.5	3.8
20.00 – 21.00	2.0	1.0	0.7	4.3	9.0	3.3	5.5	3.0	3.5
21.00 – 22.00	2.5	0.0	0.0	5.0	7.0	2.8	2.5	1.5	2.0
22.00 – 23.00	3.5	0.5	0.3	0.7	3.5	1.5	1.0	2.5	1.0
23.00 – 24.00	2.0	1.0	0.0	3.3	4.0	2.0	1.5	1.5	1.9
AVG VOL/HR	3.0	2.3	0.9	2.3	7.1	2.9	4.6	3.6	3.2

WEIGH SCALE REPORTS – DATA TAKEN AT CLAVET SITE FROM MAR 16 TO MAR 31 77

TRAFFIC VOLUMES – BY SPEED RANGE, VEHICLE GROUP AND TIME OF DAY FOR MONTH OF MARCH, 1977

	GROUP 1		GROUP 2		GROUP 3		GROUP 4		GROUP 5	
SAMPLE SIZE	DAY 180	NIGHT 180	DAY 63	NIGHT 15	DAY 100	NIGHT 47	DAY 26	NIGHT 14	DAY 180	NIGHT 180
SPEED RANGE (MPH)										
< 30	0	0	2	0	0	0	0	0	0	1
30 – 33	0	0	0	0	0	0	0	0	0	0
33 – 36	0	0	0	0	0	0	0	0	0	0
36 – 39	0	0	1	0	0	0	1	0	1	0
39 – 42	2	0	0	1	0	1	0	0	1	3
42 – 45	0	1	2	0	4	0	0	0	1	3
45 – 48	1	1	1	1	4	1	1	1	9	7
48 – 51	4	4	1	0	10	1	4	0	16	21
51 – 54	7	7	4	2	13	8	4	1	22	30
54 – 57	7	12	10	3	29	6	3	3	36	38
57 – 60	17	31	13	2	40	7	3	3	47	42
60 – 63	14	40	11	3	20	5	4	2	13	11
63 – 66	36	35	4	2	23	6	5	3	17	13
66 – 69	41	26	6	1	18	5	1	1	12	10
69 – 72	25	11	6	0	10	5	0	0	4	1
71 – 75	13	6	2	0	7	0	0	0	1	0
75 – 78	9	2	0	0	1	0	0	0	0	0
78 – 81	0	3	0	0	1	2	0	0	0	0
81 – 84	2	1	0	0	0	0	0	0	0	0
84 – 87	1	0	0	0	0	0	0	0	0	0
87 – 90	1	0	0	0	0	0	0	0	0	0
90 +	0	0	0	0	0	0	0	0	0	0

NOTE A SPEED RANGE GIVEN ABOVE AS 30 – 33, FOR EXAMPLE, ACTUALLY COVERS THE RANGE 30.00 – 32.99 ETC.

WEIGH SCALE REPORTS – DATA TAKEN AT CLAVET SITE FROM MAR 16 TO MAR 31 77

TRAFFIC VOLUMES – SAMPLES FOR MONTH OF MARCH, 1977

VEHICLE CLASS	TYPE	1 DAYS SAMPLE NO. OF VEHICLES	1 DAYS SAMPLE % OF TOTAL	5 DAYS SAMPLE NO. OF VEHICLES	5 DAYS SAMPLE % OF TOTAL	WHOLE POPULATION NO. OF VEHICLES	WHOLE POPULATION % OF TOTAL
1		1003	95.80	2687	87.93	13428	90.79
2		5	0.48	17	0.56	82	0.55
3		6	0.57	15	0.49	54	0.37
4		1	0.10	0	0.00	6	0.04
5	2	16	1.53	126	4.12	494	3.34
6	3	0	0.00	25	0.82	68	0.46
7	2–S1	2	0.19	7	0.23	28	0.19
8	3–S1	1	0.10	0	0.00	3	0.02
9	S–S2	2	0.19	21	0.69	66	0.45
10	2–2	0	0.00	0	0.00	1	0.01
11	2–3	0	0.00	0	0.00	0	0.00
12	3–2	0	0.00	0	0.00	0	0.00
13	3–S2	8	0.76	141	4.61	493	3.33
14	2–S1–2	0	0.00	1	0.03	1	0.01
15	3–3	0	0.00	0	0.00	1	0.01
16	3–S1–2	0	0.00	2	0.07	10	0.07
17	3–S2–2	0	0.00	0	0.00	0	0.00
18	3–S2–2T	0	0.00	1	0.03	3	0.02
19	2–1	3	0.29	5	0.16	28	0.19
20	4	0	0.00	1	0.03	2	0.01
21	2–2T	0	0.00	0	0.00	0	0.00
22	3–S3	0	0.00	0	0.00	0	0.00
24	2–S3	0	0.00	0	0.00	0	0.00
25	2–3T	0	0.00	0	0.00	0	0.00
26	OTHERS	0	0.00	7	0.23	23	0.16
TOTAL		1047		3056		14792	

VEHICLE TRAFFIC BY HOUR BY DAY

DAY	HOUR																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	3	0	0	0	0	0	0	0	0	0	25	59	61	46	0	1	3	3	4	0	0	0	0	0
2	2	0	0	0	0	0	0	0	0	1	0	0	0	16	66	76	66	82	41	54	27	33	38	41
3	21	12	12	2	4	10	44	101	93	55	46	49	57	78	99	98	125	120	85	82	70	62	70	32
4	23	7	4	5	9	9	35	105	98	57	63	51	46	77	107	131	135	166	123	75	47	54	39	39
5	23	21	13	8	15	10	21	37	35	44	56	51	54	77	74	84	94	107	79	60	36	33	52	28
6	25	21	21	9	6	2	13	31	24	41	61	35	66	101	115	100	82	85	70	77	64	72	59	48
7	15	6	5	5	10	14	43	109	112	53	43	50	13	0	0	0	0	1	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	38	69	52	0	3	0	0	0	0	0	0	0
9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	26	77	101	114	91	45	39	36	44	28
10	15	6	7	3	6	10	39	104	102	68	57	43	46	59	64	85	100	104	73	73	38	29	40	24
11	11	6	3	5	4	6	32	94	114	56	60	47	56	69	61	59	68	94	41	44	35	30	29	31
12	17	6	5	5	4	10	44	94	97	53	49	43	42	64	66	85	98	103	73	61	46	43	51	35
13	21	7	4	5	5	7	37	95	88	44	47	55	57	81	88	108	138	175	126	103	62	41	48	33
14	40	23	22	7	7	4	30	43	40	57	58	96	57	61	105	111	113	118	89	50	43	34	45	40
15	24	22	14	4	3	2	23	29	20	44	43	71	72	113	113	100	87	74	71	65	59	52	64	44
16	13	6	7	3	9	11	44	100	87	36	30	49	39	58	72	79	106	112	76	66	35	27	22	27
17	12	7	6	1	3	8	33	121	118	74	64	55	44	59	92	89	97	115	72	59	38	31	53	1
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

THE MOST TRAFFIC IN ONE HOUR WAS 175 WHICH PASSED OVER THE SCALE ON HOUR 18 OF DAY 13

THE HIGHEST DAILY TRAFFIC WAS 1505 VEHICLES WHICH PASSED OVER THE SCALE ON THE 4TH DAY